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INTRODUCTION

By W. T. SEDGWICK, Director.

Sanitary Research Laboratory and Sewage Experiment
Station, Massachusetts Institute of Technology,
Boston.

The present volume is the sixth in the series of reprints of essentially similar character,—namely of researches and addresses touching various aspects of Sanitary Science and the Public Health,— as these subjects have been treated during the last year or two by those connected with the Sanitary Research Laboratory and Sewage Experiment Station of a great American School of Science and Technology. Like the volumes of the same series which have preceded it, this one also owes its existence to the unflagging interest and unstinted co-operation of an anonymous friend of the Institute who, "feeling keenly the incongruity of a twentieth century civilization which, rightly enough, boasts of its achievements in mechanical, industrial and other sciences, yet regards human life so carelessly as to go on polluting rivers and harbors with vast and ever increasing streams of putrefying sewage," is determined to do whatever can be done to bring about a change for the better. Our first and most agreeable duty is to return thanks, as we hereby do, to this Donor, not only for continued financial support but also for friendly criticism and unfailing inspiration.

From the very beginning of our work Professor Charles-Edward Amory Winslow has occupied the responsible and often trying position of Biologist-in-Charge of it. This responsibility he has now laid down for another and larger field of labor. A review of the entire series of reprinted papers now comprising six volumes will prove perhaps better than anything else the extent of his influence and the scope of his researches. The larger part of whatever influence and success have been achieved by our Sanitary Research Laboratory and Sewage Experiment Station belongs to Professor Winslow; and to him the thanks not only of the Director but of all who have been associated with him in a work which he has so successfully prosecuted are hereby gratefully tendered.

Professor E. B. Phelps continues to occupy with us the same important position as heretofore, namely, that of Research Chemist and Bacteriologist, and the Staff of the Laboratory and Station have been strengthened by the addition as Research Associate of Mr. George T. Palmer, upon whom much of the responsibility for the actual conduct of our investigations now falls; of Professor S. C. Prescott, to whom we are glad to be at liberty to turn for advice and suggestions; and of Mr. Selskar M. Gunn, recently appointed Instructor in Sanitary Biology at the Institute after an extensive experience as Assistant Bacteriologist to the State Board of Health of Iowa, and, later, Health Officer of the City of Orange, N. J.

Until very recently the problems connected with the sanitary disposal of ordinary city sewage have been deemed of so much importance that the principal energy and resources of our Experiment Station have been concentrated upon these. And even yet we cannot say that all or even the most important of these problems have been satisfactorily solved. At the same time there is today a widespread agreement among experts as to the general methods which should be employed in the disposal of the city sewage. It is now well recognized, for example, that there is no one solution of this vast and varied problem. In any particular case much depends upon the location, climate, soil, and other intrinsic or environmental conditions. Sometimes disposal by simple dilution in sea-water suffices. Sometimes this is highly objectionable. If dry and sandy soil abounds in close proximity to a particular city, then disposal by intermittent filtration may be the best solution of the problem. If on the other hand, the sewage of a manufacturing city is strongly acid, sand filtration without special preparatory treatment of the sewage, depending as it does upon bacterial activity, may be quite out of the question. If the city to be drained is situated upon a lake from which drinking water must be drawn, a difficult problem arises, since disposal in lakes, even at a great distance from the intake of waterworks, may prejudice the purity of public water supplies.

No better evidence of the many sidedness of the sewage problem or of the variety of solutions applicable to its various phases is needed than can be found in the timely and valuable treatise on "Sewage Disposal" which has lately issued from the press under the authorship of three graduates of the Institute of Technology, namely, Professor Leonard P. Kinnicutt, Head of the Chemical Department of the Worcester (Mass.) Polytechnic Institute, Professor C.-E. A. Winslow, Assistant Professor of Sanitary Biology and Biologist-in-Charge of the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology, (from which the present volume of Contributions and those that have preceded it have come) and Mr. R. W. Pratt, Chief Engineer of the State Board of Health of Ohio. Those who would appreciate the magnitude, the variety and the difficulty of the sewage disposal problem in the United States would do well to consult this important volume, no small part of which has been the outgrowth of the series of researches recorded in the several volumes of the present series of "Contributions."

It has been the often repeated wish of the Donor from the outset that our Laboratory and Station should not only make original contributions to the solution of the difficult problems of sewage disposal, but should also take an active part in the education of the public along lines of cleanliness, sanitation, public health, and more wholesome living. It is interesting to note accordingly, that, of the present volume, three of the papers and nearly two-thirds of its pages, represent purely scientific and original work; while the remainder are devoted to public exposition, popular information, or educational aspects of Sanitary and Public Health Science.

Massachusetts Institute of Technology.

Boston, September, 1910.

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ON THE MILLS-REINCKE PHENOMENON AND HAZEN'S THEOREM CONCERNING THE DECREASE IN MORTALITY FROM DISEASES OTHER THAN TYPHOID FEVER FOLLOWING THE PURIFICATION OF PUBLIC WATER-SUPPLIES.*

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AND
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Health Officer of Orange, New Jersey

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I. INTRODUCTION.

It is nowadays commonly understood that the purification of a polluted water-supply produces a marked decrease in the mortality from typhoid fever among persons using the water for drinking and other domestic purposes, but it is not as yet generally recognized that such purification produces also a marked decrease in deaths from other diseases.

In 1893–94 it was observed, independently, by Messrs. Hiram F. Mills, C.E., of Lawrence, Massachusetts, and Dr. J. J. Reincke, of Hamburg, Germany, that the purification of the polluted public water-supplies of Lawrence and of Hamburg, respectively, was producing a notable decline in the general death-rate of each of these cities. The attention of Mr. Allen Hazen was about the same time turned to the subject, and some years later, in a paper presented to the International Engineering Congress held at the St. Louis Exposition in 1904, he drew from an examination of the death-rates of certain cities which had radically improved polluted water-supplies the following conclusion:

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.

This novel statement has not hitherto received the attention which it deserves, and in view of this fact, as well as in order to test the range and accuracy of Mr. Hazen's conclusion, and also if possible to find an explanation for it, we have undertaken a careful examination of the vital statistics of a number of cities each of which has changed more or less suddenly from a polluted to a purified water-supply.

On August 14, 1908, we published in "Science" a preliminary communication announcing in part the results of our study and confirming Mr. Hazen's statement. We also contributed to the volume on "Tuberculosis in Massachusetts," prepared by the Massachusetts State Committee for the International Congress on Tuberculosis held in Washington, D.C., September 21 to October 12, 1908, and published in Boston in 1908, a paper entitled "On an Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis."

As will appear beyond, circumstances arose not long after the publication of our preliminary communication which made it seem desirable to repeat some portions of our work, and especially to take into consideration questions relating to the constancy of increase of population ordinarily estimated for American cities between census years. Some delay has thus been caused, but we now present the complete paper, which we venture to believe has meanwhile gained both in scope and in trustworthiness.

II. THE MILLS-REINCKE PHENOMENON.

Shortly after the introduction of a filtered and purified water-supply into Lawrence, Massachusetts, in September, 1893, it was observed by Mr. Hiram F. Mills, C.E., a member of the State Board of Health of Massachusetts, then a resident of the city of Lawrence and chief engineer of the company controlling the water power of that city, that a marked decrease in the general death-rate of the city, and not merely in the death-rate from typhoid fever, was taking place. A few months earlier (May, 1893) filtration of the public water-supply had likewise been established for the city of Hamburg, Germany, and there also it was observed by Dr. J. J. Reincke, health officer of that city, that the general death-rate was declining more rapidly than could possibly be accounted for by the deaths from typhoid fever alone. To this important discovery, made thus independently by Mr. Mills in Lawrence and Dr. Reincke in Hamburg, we have, because of its fundamental and far-reaching significance, applied the name of *The Mills-Reincke Phenomenon.*

Mr. Allen Hazen, the now well-known civil and sanitary engineer, who had long been more or less closely associated with Mr. Mills, visited Europe early in 1894, and while in Hamburg conferred with Dr. Reincke. He was impressed with the favorable results of filtration as observed and described by Dr. Reincke, and on his return to America he mentioned Dr. Reincke's observations to one of the writers (W. T. S.). He also stated in the first edition (1895) of his "Filtration of Public Water-Supplies" (p. 177):

> The death-rate [of Hamburg] since the introduction of filtered water has been lower than ever before in the history of the city, but as it is thought that other conditions may help to this result no conclusions are as yet drawn.

To this statement he appended in a later edition a table showing the deaths in Hamburg from typhoid fever and from all causes 1880–98, i.e., before and after the introduction of filtration.

III. DR. REINCKE'S OBSERVATIONS ON THE RELATION OF TOTAL DEATH-RATE TO WATER-SUPPLY IN HAMBURG, GERMANY, 1894–97.

The Hamburg filters began their work in May, 1893, and for that year the total death-rate showed an extraordinary decrease from that of preceding years, and a greater decrease than could be accounted for by the drop in the typhoid fever death-rate alone. Dr. Reincke's observations concerning this remarkable phenomenon were published from time to time in his Annual Reports[1] and may be quoted (in literal translation) or summarized as follows:

> In the year 1893 . . . . the total death-rate of Hamburg was 20.4 per thousand living. The mortality has never been so low before . . . . since the beginning of vital statistics in Hamburg in 1820. . . . . Manifestly the chief explanation of this favorable result is that the cholera of 1892 carried off an extraordinarily large number of people, especially of the weaker and less resistant, a part of whom would otherwise not have died until 1893. Whether the great improvement of the water has been of influence can be ascertained only after several years. The figures given in connection with infant mortality speak, however, strongly for this theory (Report for 1893, p. 15).

---

[1] *Berichte des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates.*

For 1894 Dr. Reincke found the total death-rate to be 17.9 per thousand living.

> Thus the mortality has receded still lower even than that of last year, which, as has been said, was the most favorable since the beginning of recorded vital statistics in Hamburg. . . . .
>
> It is not altogether easy to offer a sufficient explanation of this favorable result. That the effect of the cholera of 1892 in carrying off prematurely many weak individuals is still operative, is not very probable, for the favorable conditions of 1894 appear in no age group so strikingly as among infants under one year, all of whom have been born since the epidemic. The death-rate of such infants is 201.9 per thousand [under one year of age] for 1894, as compared with a fifteen-year average of 287.1.
>
> On the other hand, there is greater reason than in the preceding year for attributing a considerable share in the altered conditions to the improved water-supply, and the results for 1892 and 1893 of the influence of the water on the mortality of children from diarrhea and gastro-intestinal diseases are freshly confirmed (Report for 1894, pp. 11, 13).

In 1895 the total death-rate was 18.9 per thousand living, i.e., 1.0 more than in 1894.

> Nevertheless the mortality was still more favorable by 2.7 per thousand than in 1890, the most favorable year before the introduction of filtration, and more favorable by 5.8 than the mean of the ten years before the cholera epidemic, i.e., 1882–91 (Report for 1895, p. 11).

For 1896 the total death-rate is reckoned at 17.1 per thousand living, the lowest ever observed in Hamburg up to that time.

> Undoubtedly, the especially favorable result for this year is to be attributed chiefly to the cool wet weather from the middle of June to the middle of July, on account of which the high infant mortality of the summer was speedily cut down. . . . . That the year has passed as favorably as the three preceding years is fresh confirmation of the fact that *since the filtration of the drinking water the health conditions in Hamburg have improved in a quite extraordinary manner.* (Ist eine neue Bestätigung dafür, dass seit der Filtration des Trinkwassers sich die Gesundheitsverhältnisse Hamburgs in ganz ausserordentlicher Weise verbessert haben.) (Report for 1896, p. 11, italics ours.)

For 1897 the total death-rate of Hamburg "Stadt" (exclusive of the suburbs) is reckoned as 17.0 per thousand living. Again no rate so low had ever before been observed in the history of the city (Report for 1897, p. 12).

All the more weight must be given to the statistical statements made above because these were based upon an annual official enumeration of the population.

IV. DR. REINCKE'S STUDIES ON THE RELATION OF INFANT MORTALITY TO WATER-SUPPLY IN HAMBURG AND ALTONA, 1893–97.

In Dr. Reincke's Annual Report for 1892[1] we find a searching examination of the effect of water-supply upon infant mortality (particularly as due to gastro-intestinal diseases), which, because of its early date and its obvious importance for all students of the relations of polluted water to public health science, we shall either quote in careful translation or summarize, as follows:

> It is usually assumed that the greater part of the deaths from gastro-intestinal diseases (*Brechdurchfall*)[2] in summer is to be explained by the high summer temperature, particularly through the action of warmth on the principal food of infants, i.e. milk. Our local observations, however, indicate that the matter is somewhat more complicated than this (p. 10).

Tables and diagrams are given of deaths from diarrhea and gastro-intestinal diseases, by months, for Hamburg and for Altona, with the mean monthly temperatures, 1871–92. In connection with these it is pointed out that the parallelism between deaths and high temperatures is not well marked, but that, on the contrary, there have been distinct outbreaks of these diseases during cold-weather periods. Also, that the curves for winter deaths of infants under one year from gastro-intestinal diseases are not parallel in Hamburg and Altona, as is the case with those of the summer period Reincke was unable to discover similar winter outbreaks in any other German city except, for certain years, in Berlin. We quote further and at length:

> In Bockendahl's "Generalbericht über das öffentliche Gesundheitswesen der Provinz Schleswig-Holstein für das Jahr 1870," p. 10, we read: "Still more striking was an epidemic of gastro-intestinal diseases in Altona in January which proved fatal to 43 children. As the cases were observed in all parts of the city and the medical officer was unable to explain the phenomenon, he procured from the Gas and Water Company a statement regarding any interruptions in the supply of pure water to the city during the year 1870. He then learned that the city was supplied during a few days in January with unpurified Elbe River water. However little reason there may

---

[1] *Bericht des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates für 1892*, published without date, but presumably late in 1893.

[2] We have not been able to find any exact English equivalent for the term *Brechdurchfall*, which denotes literally a condition characterized by diarrhea and vomiting. Mr. Hazen's rendition "cholera infantum," employed in his translations from Dr. Reincke in Appendix II of his "Filtration of Public Water-Supplies," does not appear to be allowable. *Brechdurchfall* is applied to both adults and children, but more frequently to the latter because gastro-intestinal disturbances are much more common during the early years of life. Throughout our translations of, and references to, the writings of Dr. Reincke and his associates, we shall render the term, with an approximation to accuracy, sometimes as "gastro-intestinal disorders," and sometimes, especially when it is applied to fatal cases, as "gastro-intestinal diseases," without, however, necessarily implying by the latter phrase the existence of discoverable lesions.

be for regarding the connection between these two circumstances as proved, it is only proper that at all times interruptions in the pure water service be closely watched, because only in this way can reliable conclusions be reached and dangers be avoided. . . . . "

Dr. Kraus, who was at that time the medical officer of Altona, and who made the studies upon which Bockendahl's statement is based, subsequently became health officer of Hamburg; and, in a more lengthy opinion . . . . dated 1874, earnestly advocating the establishment of sand filtration in Hamburg, supported his position with the above observations, although with the caution that they are not to be regarded as entirely conclusive. In his annual report on the vital statistics of Hamburg for 1875 he suggests (p. 17) that the addition of unfiltered Elbe water to milk had probably been connected with the infant mortality of Hamburg, which mortality was very high in comparison with that of London (dass der Zusatz von unfiltrirtem Elbewasser zu der Milch wahrscheinlich an der im Vergleich zu London sehr hohen Sauglingssterblichkeit Hamburgs betheiligt sei.) He later repeated this opinion both in oral and in written statements.

Meantime so much material for observation has accumulated that his view may now fairly be regarded as proved. . . . .

Years ago, on observing the epidemic behavior of typhoid fever, in Altona . . . . I suggested that at the Altona waterworks disturbances in the action of the filters occurred in connection with frost, causing the distribution of water insufficiently purified. Wallichs of Altona, on the ground of further observations on typhoid fever, has come to the same conclusion, and lately Robert Koch, on the occasion of the small winter epidemic of Asiatic cholera in Altona, has proved that our hypothesis is correct. When open filters are cleaned in cold weather, it is a matter of common observation that the germs in the water are not sufficiently held back by the filters; and, as an actual fact, simultaneously with these disturbances of filtration there have occurred not only the explosive typhoid outbreaks of 1886, 1887, 1888, 1891, and 1892, and the Asiatic cholera outbreaks of 1871 and 1893, but also the increases of gastro-intestinal disorders in Altona. It can, therefore, no longer be doubted that these phenomena stand in the relation of cause and effect. It is thus explained also why in warm winters, as above mentioned, there have been no such outbreaks, and why gastro-intestinal disorders in winter have not been parallel in Hamburg and Altona.

In Hamburg the winter increases [of gastro-intestinal disorders] cannot be explained so simply. It seems probable, rather, that northeast storms, through the high tides which they cause, bring polluted water in greater quantity to the intake of the waterworks. It cannot be demonstrated that every such occurrence has caused an increase in infant mortality, but in many instances a noteworthy coincidence occurs. . . . . This point could be decided only by careful bacteriological determinations, and we have some such evidence for the last months of the year 1892, when daily bacteriological examinations of the city water were made at the Hygienic Institute, altho examinations of the river water itself were not begun until later. It was thus found that the bacterial content of the water varied between 200 and 600 at the end of October and the beginning of November; that it rose after November 19 to about 3,000; after December 4, to 4,000–5,000; and on December 18, to 7,500; and finally dropped rapidly in January to 200–500. On December 4 there occurred a storm-tide 2.6 m. in height, following a series of moderate high tides, and the December increase in infant mortality corresponded with the increase in bacteria in the water-supply mentioned above.

[TABLE 1.]

STRALAU WATERWORKS, BACTERIA PER C.C.			DEATHS FROM ACUTE INTESTINAL DISEASES		
			TOTAL	GASTRO-INTESTINAL DISEASES	
				At All Ages	Infants under One Year of Age
1886					
March 23	145	March 21–27	...	4	4
March 30	2,300	March 28–April 3	34	20	18
April 6	500	April 4–10	106	49	46
April 13	125	April 11–17	99	46	44
April 20	360	April 18–24	56	25	25
April 27	105	April 25–May 1	46	22	22
1888					
March 1	16	March 11–17	24	4	4
March 15	3,600	March 18–24	76	29	29
		March 25–31	73	25	23
April 3	440	April 1–7	47	17	17
		April 8–14	47	21	21
April 16	125	April 15–21	50	20	18
		April 22–28	27	15	15
		April 29–May 5	28	12	12
1889					
January 16	112	January 13–19	28	4	4
		January 20–26	35	9	8
February 1	1,730	January 27–February 2	38	12	12
		February 3–9	65	17	17
February 15	1,600	February 10–16	86	22	22
		February 17–23	59	13	13
		February 24–March 2	35	8	8
March 4	2,400	March 3– 9	47	13	12
		March 10–16	54	22	22
March 18	4,800	March 17–23	112	53	52
		March 24–30	215	118	116
April 1	264	March 31–April 6	120	61	60
		April 7–13	82	40	38
April 15	98	April 14–20	44	18	14
1891					
December 15, 1890	123	December 21–27, 1890	22	6	6
January 2, 1891	450	December 28, 1890–January 3, 1891	31	4	4
		January 4–10	25	3	3
January 15	1,325	January 11–17	25	6	6
		January 18–24	18	2	2
		January 25–31	36	7	7
February 1	13,000	February 1– 7	61	12	12
		February 8–14	158	61	61
February 16	4,000	February 15–21	160	50	50
		February 22–28	104	42	41
March 3	120	March 1– 7	88	29	29
		March 8–14	68	20	20
March 17	310	March 15–21	43	14	14
		March 22–28	38	10	10
April 1	85	March 29–April 4	28	9	9
		April 5–11	41	9	9
April 15	800	April 12–18	39	13	13
		April 19–25	46	16	16
May 1	140	April 26–May 2	25	11	11
		May 3– 9	49	19	18
1893					
?		February 5–11	23	4	9
?		February 12–18	56	20	19
?		February 19–25	110	41	41
?		February 26–March 4	110	40	39
?		March 5–11	69	20	19
?		March 12–18	39	10	9

A further support for this theory is found in the conditions at Berlin, where, likewise, frost has repeatedly interfered with filtration. The above table gives the deaths from acute intestinal diseases, for several winter periods in which striking increases in mortalities in these diseases have appeared. It is obvious that, of the deaths enumerated in the first column, a predominant number is among little children. For comparison the bacteriological examinations are given, according to Plagge and Proskauer, of the tap water from the Stralau waterworks. Unfortunately the figures for 1892 are wanting.

No one can doubt, after this demonstration, that here also the delivery of insufficiently purified water every time cost the lives of many children. Still more striking is the evidence, from the publications of the Statistical Office at Berlin, that other parts of the city, supplied with better water from the Tegel works, completely escaped these increases in mortality, precisely as was the case in the well-known typhoid epidemic of February and March, 1889.

. . . . The fatal effects of the water are not confined, however, to those infants dying from well-defined intestinal diseases, for there is a large number besides who must have fallen victims with less striking intestinal symptoms. It appears, furthermore, that almost the only children affected were those not nursed by their mothers or by wet-nurses but fed on the milk of animals or other substitutes, which were mixt with more or less water.

So much for the winter conditions. As for the summer, the work of Plagge and Proskauer shows that the filters have then also occasionally delivered bad water. What influence this may have had is difficult to determine, since at that season gastro-intestinal disorders show ordinarily a high prevalence. But doubtless the influences of weather and water go hand in hand. This hypothesis is still more probable for Hamburg, because there, with the river water diminished during the summer months, the tides easily run up the river [carrying sewage to the intake] even without the aid of storms. This hypothesis is supported by the extraordinary prevalence of gastro-intestinal disorders in the unusually dry warm years of 1886, 1887, and 1892. If this be the case, when the intake is moved higher upstream and sand filtration is started, we may expect a substantial decrease of infant mortality. Not only should the winter increases entirely disappear, but those of the summer ought to be notably diminished. [How well this prophecy was borne out is shown by the table given on p. 121 of the "Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert" published some years later, in 1901.] Moreover, it is not the infants only who will be benefited, for, as the Berlin figures show, there are also many cases of gastro-intestinal disorders among children from one to five years of age, and even adults do not entirely escape (pp. 13–17).

We may mention parenthetically that many of the valuable observations just quoted have been presented in English by Mr. Hazen in the first (1895) and subsequent editions of his "Filtration of Public Water-Supplies," Appendix 11.

Dr. Reincke's report[1] for the following year (1893) gives the mortality under one year of age, reckoned per thousand living in that age-group, for 1893 and earlier years, as follows (p. 17): 1885, 277.2; 1886, 368.8; 1887, 347.5; 1888, 289.8; 1889, 316.5; 1890, 276.3; 1891, 288.7; 1892, 404.8; 1893, **240.2**.

[1] For full title of reports see footnote, p. 492.

> How uneven is the distribution by age months of this mortality of infants under one year of age, is shown by the following table.

Economy of space forbids our reproducing in full the table (p. 40) referred to, but we present a summary of it (Table 2).

TABLE 2.

Ages of Infants Dying under One Year, by Months.

	Average 1884–92 Inclusive Percentage	1893 Percentage		Average 1884–92 Inclusive Percentage	1893 Percentage
In the 1st month	24.2	27.0	In the 7th month	5.6	5.7
" " 2d "	12.9	14.3	" " 8th "	5.2	4.5
" " 3d "	11.0	11.9	" " 9th "	4.8	4.2
" " 4th "	9.1	9.6	" " 10th "	4.5	3.8
" " 5th "	7.8	7.2	" " 11th "	4.2	3.0
" " 6th "	6.5	5.9	" " 12th "	4.0	2.9
				100	100

Under "diarrhea and gastro-intestinal diseases" (Durchfall und Brechdurchfall), the following figures are given for the deaths of infants under one year of age for these causes by years:

1884	1,143	1889	1,557
1885	1,189	1890	1,198
1886	1,601	1891	1,500
1887	1,758	1892	2,541
1888	1,063	1893	857

> Since I expressed myself in detail on these causes of infant mortality in my report for 1892 [already quoted above], it suffices for the present year [1893] to call attention to the highly significant decline in the number of these deaths and to the fact that this year the increase in mortality in December, often previously observed, is entirely absent. From the thorough studies recorded in last year's report it is highly probable that this favorable result is to be attributed largely to the filtration of the public water-supply, altho this point can be positively decided only after the experience of future years. Especially noteworthy is the considerable increase of deaths from these diseases in the second half of September, following a temporary pollution of the water which led at the same time to an outbreak of Asiatic cholera (pp. 43–44).

Three years later Dr. Reincke repeats a portion of the above table, adding to it the deaths from diarrhea and gastro-intestinal diseases for 1894, 1895, and 1896, which were 708, 918, and 767, respectively (see our Chart 1). He may well have remarked, in view of these figures together with the increasing population:

> In no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these (Report for 1896, p. 46).

V. FURTHER DISCUSSION OF THE INFLUENCE OF WATER-SUPPLY UPON DEATH-RATES IN "DIE GESUNDHEITSVERHÄLTNISSE HAMBURGS IM NEUNZEHNTEN JAHRHUNDERT" (1901).

In 1901 there appeared a comprehensive treatise on the "Sanitary History of Hamburg in the Nineteenth Century," prepared under the editorship of Dr. Reincke.[1] In this work the declines in the total death-rate and in the death-rates from various diseases following the introduction of filtration into Hamburg are still further considered, and additional evidence is given for the existence of a relation between water-supply and gastro-intestinal diseases (particularly of infants). The observations on these points we have abstracted, mainly in literal translations and at some length, as follows:

1. General Death-Rate.

In the century curve of the general death-rate . . . . four peaks of specially high mortality stand out predominantly; these are the cholera years 1831 and 1832, 1848, and 1892 and the small-pox year 1871. Between them lies a greater number of lesser elevations, which are likewise to be attributed to greater or smaller epidemics of infectious diseases. . . . . Following each of these peaks there sets in regularly a compensatory decline in mortality.

Entirely different from these declines is that which set in after the cholera epidemic of 1892; for not only was this deeper than any other before it, but it has also lasted now throughout eight years—the beneficent result of the filtration of the water-supply which has been in operation since 1893 and to which we shall repeatedly return in connection with our consideration of the mortality from particular diseases (p. 90).

Comparing the twenty-five years 1872–1896 with the following four years, the average annual mortality has dropped from 25.0 to 17.2, a decrease of 7.8 per 1,000. In this improvement at least 6.1 per 1,000 may be regarded as due to general measures of sanitation, and of this again 3.0 at the very least as due to the betterment of the water by filtration. In this there have been reckoned for the infants under one year only 1.8 instead of 2.7, to avoid by any chance putting the figure too high; for cholera 0.8, and for typhoid fever 0.4 per 1,000. Even leaving the cholera out of account, an average improvement by at least 2.2 per 1,000 must be acknowledged. That gives, even with this thoroughly cautious and conservative calculation, for a population of, in round numbers, 340,000 (as the number stood in 1872), an annual number of deaths 748 fewer, and for the present population of 700,000, 1,540 deaths fewer in a year, which are to be accredited to the filtration of the drinking water. Undoubtedly, however, the real figures are much higher.

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[1] *Die Gesundheitsverhältnisse Hamburgs im neunzehnten Jahrhundert*, den ärztlichen Theilnehmern der 73. Versammlung deutscher Naturforscher und Aerzte gewidmet von dem Medicinal-Collegium, Hamburg (Verlag von Leopold Voss), 1901. Translating freely, we shall apply to this work the English title given above—the term "history" being suggested by Dr. Reincke's preface. As the sections from which we quote bear no signatures, we assume that these sections are editorial and hence to be credited—at least in the main—to Dr. Reincke; many of the statements which we have quoted from his Annual Reports are, in fact, either paraphrased or amplified in the later work. In making this assumption we hope that we do no injustice to any of Dr. Reincke's collaborators.

Through the improvement of the water-supply already discussed and the other contemporaneous measures of sanitation, Hamburg has caught up with most of the arger German cities, which hitherto had had more favorable sanitary conditions, and has surpassed many (pp. 310, 312).

2. Infant Mortality, Diarrhea, and Gastro-intestinal Diseases.

The term "Infant Mortality," as we shall use it here, has a special significance corresponding to the German "Saüglingssterblichkeit, d.i. der Sterblichkeit der im ersten Lebensjahre stehenden Personen," i.e., the mortality of infants under one year of age. As 90 per cent of all deaths from diarrhea and gastro-intestinal diseases (Durchfall und Brechdurchfall) in Hamburg in the nineteenth century occurred among infants under one year of age, we combine these heads as above.

> It is certainly in consequence of sanitary improvements that, in spite of the growing factory-working population of the city, the *infant mortality has declined so extraordinarily since 1893.* And as a discussion, beyond, on gastro-intestinal diseases will show, *this abrupt and lasting improvement is to be attributed solely to the filtration of the drinking water* (Diese plötzliche und andauernde Verbesserung ist allein der Filtration des Trinkwassers zu danken) (p. 145, italics ours).

Under diarrhea and gastro-intestinal diseases it is noted that the mortality under this title is not statistically complete, since most of the deaths of infants from atrophy and debility (Atrophie und Lebensschwäche) really belong here. The evidence for this is found in their parallelism in seasonal and yearly prevalence.

> Manifestly the as yet unidentified germs of these diseases are ingested by infants with their nourishment—never, however, in mother's milk, but only in artificial substitutes, especially cow's milk—which in some way or other has been contaminated with pathogenic germs. . . . . Among the dangerous contaminations of milk, a great part was played in Hamburg, until 1893, by the unpurified Elbe water, which was introduced into all the dwellings by the city water system. . . . . But since the water has been filtered, a gratifying decline in infant mortality has set in [see our Chart 3] (pp. 149, 150).

> Since diarrhea and gastro-intestinal diseases attack chiefly infants under one year [who contributed 90 per cent of the deaths from these causes in Hamburg in the nineteenth century], and as no other diseases of infants claim nearly as many victims, it is evident why the century curve for these causes of death shows an extraordinary similarity to the curve of total infant mortality. Divergences occur only in exceptional years when for a time infants died in increased numbers from other diseases, or adults from diarrhea (p. 207).

The data given below concerning the connection of disease with drinking water suggest, moreover, the question whether the rise of the century curve since the '60's does not stand in a definite connection with the extension of the public water-supply of unfiltered Elbe water. The mean curve by months agrees, as would be expected, almost completely with the curve of deaths of infants from gastro-intestinal diseases. . . . . It virtually follows the atmospheric temperature, for continuous hot days usually unmistakably increase the number of cases of sickness. This subject, however, still needs for complete clarification much more thorough investigation than it has yet had. It must not be forgotten that hot days in May and June scarcely increase gastro-intestinal disorders. Furthermore, in midsummer the temperature is not the only decisive factor, for atmospheric humidity, the distribution of storms, and other factors which are of influence either upon the dissemination of pathogenic organisms or upon their multiplication in milk and other foods, also co-operate.

To *one* of the factors, which plays a part in the dissemination of the germs, attention has been drawn in Hamburg by the fact that the mean curve by months shows here a second rise, which, tho small, nevertheless reached in certain years (e.g., in January, 1883, 1890, 1892; in February, 1889; and in December, 1885, 1886, 1888, and 1891) a very considerable height. This rise occurred always in the winter, but cannot possibly be explained by colds, by life in small, badly ventilated rooms, by injury of milk consequent on heating, or by damage done by Christmas feasting; for, so far as we have been able to determine, in other places of similar climate, the winter increase in gastro-intestinal disorders does not, under ordinary circumstances, take place. Moreover, the case is very different in Hamburg in the various years. And above all, it has ceased since the city water has been well filtered (Und vor Allem da sie aufgehört hat, seitdem das Wasser der städtischen Wasserleitung gut filtrirt wird).

The suspicion cast upon the unpurified Elbe water by these facts is strengthened by observations in other places. In this connection what happened in the district of the Stralau waterworks at Berlin[1] is of great interest. When the waterworks delivered badly filtered water, the population of the district supplied from Stralau responded at once with an increased mortality of infants from gastro-intestinal diseases, which occurred moreover exclusively among infants artificially nourished. A similar observation was recorded in the report mentioned (p. 13) regarding the Altona[1] waterworks as early as 1870, and it was further stated that every time disturbances took place in the operation of the filters at the Altona works, the prevalence of gastro-intestinal disorders increased in the city. Finally, it was recounted that after several high tides in November and after an especially high "storm-tide" on the 4th of December, 1892, bringing about a heavy pollution of the Elbe water at the waterworks intake (proved bacteriologically), an increased infant mortality occurred in Hamburg. The bacterial content of the Elbe River water rose at this time from 200–300 per c.c. to 7,500. Such observations led of necessity to the conclusion, that in other years also when similar events took place the polluted city water was to blame. As already stated (p. 50) there is a possibility that filth particles and pathogenic germs emptied into the Elbe with sewage are driven occasionally by the tide upstream, both to the old and the new waterworks intakes. When this happened there undoubtedly followed as a rule a pollution of the public water-supply, until this danger was eliminated by the establishment of sand filtration and the regular stoppage of pumping at high tide. This danger was not always of the same magnitude, but varied both according to the amount of fresh water coming down, which made difficult or easy the upstream movement of the tide-wave, and also according to the height of the tide-wave coming in from the sea and influenced by wind and weather (pp. 208–9).

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[1] For fuller accounts of the phenomena at Berlin and Altona see *Jahresb. über die medizinische Statistik des Hamburgischen Staates fur 1892;* translations given above, pp. 494–97.

Next follows a description of float experiments, by which it was determined how high the tides would have to be, at various stages of the river, to drive water from the outfall of the main trunk sewer upriver to the old and (since 1893) new waterworks intakes, located 6.3 and 8.5 km. upstream, respectively.

Of course the summer months, with their lower river levels, are by far the most dangerous; there appear, however, extraordinary differences in individual years. On the one hand, there are wet summers with proportionately high fresh water stages, and, on the other, dry years in which the level of the river sinks very low in the hot season. There are also mild, rainy winters in which the river remains high, as well as those in which the whole river-basin freezes up and all the precipitation remains lying on the ground as snow, so that the flow of the river becomes very scanty. Hence for our purposes the separate years must be closely studied (p. 210).

Then follow tables which lack of space forbids us to reproduce, showing, for the period of 1877–93, the varying stages of the river and the exceptionally high tides, and the time relations of these two sets of phenomena.

If the data in these tables be now compared with the tabulations of the contemporaneous deaths from gastro-intestinal diseases (p. 220), it appears clear that the dry years, with subnormal river stages in the late summer and fall (1877, 1878, 1883–1887, and 1892) and with numerous unfavorable tides, have been especially characterized by deaths from these diseases; but that in the driest year of all, 1893, the significant rise in deaths which was to be expected did not take place. It must be concluded from this that low river stages and higher prevalence of these diseases are not merely independent parallel consequences of a greater summer heat, for in that case gastro-intestinal disorders would have been worse than ever in 1893; but that since 1893 there has been broken a link in the chain which previously connected summer gastro-intestinal disorders with the low water. And that break has come with the filtration of the drinking water begun in 1893. This is confirmed, moreover, by observations of all subsequent years down to the end of the century, during which the low waters of the autumns of 1895, 1898, and 1900 have had no perceptible influence whatsoever upon gastro-intestinal disorders.

Without doubt, therefore, the summer gastro-intestinal disorders of children have been largely increased by the city water, so long as this was not filtered The process may be pictured as consisting simply in the dissemination of the infective agents in kitchens, on utensils, on bottles, on the hands of mothers and nurses, or in the milk itself, in greater quantities through the water than in other ways. The germs then multiply more or less, according to the cleanliness of the people and the condition of their dwellings and according to the weather, and, in greater or less numbers, are ingested by infants with their food.

The conditions favoring gastro-intestinal disorders in winter are not so clear, altho these also threw suspicion on the water. It is not difficult, in fact, to discover for those winter seasons in which the deaths from gastro-intestinal diseases rose abnormally, storm-tides upon which the blame could be laid; but in our table are found many high tides which apparently had no effect upon these diseases—in particular, all the storm-tides of the autumn equinox. From these a sceptic could derive justification for disputing altogether the connection between polluted water and gastro-intestinal disorders; he could also adduce the fact that before the sewerage of Hamburg and before the introduction of the public water-supply winter increases in gastro-intestinal diseases had appeared, e.g., in 1838 and 1845; and that even after the establishment of filtration, e.g., in March, 1895, there had been observed once more an increase in deaths from these diseases.

On the other hand, we may reply that the winter rises in the '30's and '40's took place in such small numbers that inferences cannot safely be drawn from them. And if any increase of these diseases did in fact take place in those years, that would not prove that the Elbe water was not to blame, for, in fact, before 1848 water was freely taken from the river, which, in former times, may have been badly polluted upstream. . . . .

Neither can the rise of gastro-intestinal diseases in March, 1895, decide the question, if the scant excess of deaths be given due weight, for in those first years of filtration the management of the waterworks still had difficulties, now entirely overcome, to contend with, arising in very cold weather with the cleaning of the filters. It appears, in fact, from reports in my possession on the bacteriological control of the filters in 1895, that in February and March of that year individual filters repeatedly worked imperfectly, so that a few of the infective agents of these diseases may have slipped through. . . . .

On comparing the two tables on page 211 and page 220, it is found that the high stages of the river caused by melting snow [at certain times] did not have the slightest influence on the number of deaths from gastro-intestinal diseases, while in January, 1883, as also in the beginning of the year 1845, the increase of deaths from these diseases coincides with a much swollen river. Before drawing any conclusions from these observations, further experiments must be awaited, and the conditions in other cities be thoroughly compared.

Meanwhile we must be content to have established the fact that the unpurified city water has, until the inception of filtration, contributed heavily to the spread of gastro-intestinal diseases (pp. 210–16). [The italics are ours.]

The decline in infant mortality is of special interest because in this we see a result of the filtration of the drinking water which has exceeded all expectation and has materially enriched our knowledge of the propagation of gastro-intestinal disorders. . . . . If therefore the whole improvement . . . . cannot be ascribed to these diseases and hence to the results of better water, certainly the overwhelming majority of cases also belongs in this category (p. 310).

We quote also the following with reference to the relation between gastro-intestinal disorders and typhoid fever:

Formerly, disturbances in the operation of the filters at the Altona waterworks repeatedly appeared, especially in very cold weather, which made the proper cleaning of the filters difficult or impossible. At such times unfiltered or insufficiently filtered water entered the distribution system, whereupon the health of the people would react at once with the appearance of cases of gastro-intestinal disorder, a sure sign to the Altona physicians that two to three weeks later typhoid cases would follow (p. 234).

Examples of such outbreaks are given, characterized as sudden in onset, restricted to the Altona district, falling in seasons otherwise unfavorable to typhoid propagation, and as having been completely absent since the improvement of filtration in Altona.

A similar local and explosive typhoid outbreak occurred in Hamburg in 1893 ("Jahresbericht für 1893," p. 55). On a wharf on the south bank of the Elbe, where the laborers were provided, for drinking purposes, with Elbe water purified by a filter of special construction . . . . 100 laborers suddenly fell sick with gastro-intestinal disorder, and 19 of them developed typhoid. Closer investigation revealed the fact that shortly before the outbreak of the sickness the filter had been "cleaned" and that its efficiency had for a while been very much reduced (p. 235).

. . . . Instances from the winter season are much more characteristic, for then the influences of the summer heat have quite ceased. A few are summarized in the table below [Table 3].

[TABLE 3.]

DEATHS FROM GASTRO-INTESTINAL DISEASES AND CASES OF TYPHOID FEVER, BY WEEKS.

	WEEK NUMBERS [FROM BEGINNING OF EACH YEAR].																					
	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
1888–89																						
Gastro-intestinal diseases	28	**57**	31	21	15	10	17	**43**	**46**	36	28	24	17	11	15	10	43	54	**83**	60	21	..
Typhoid fever	42	32	46	**83**	46	54	32	33	46	**92**	**75**	48	41	50	40	30	45	41	55	80	**112**	57
1890																						
Gastro-intestinal diseases	..	..	..	..	..	..	..	..	..	..	..	..	17	24	17	42	**64**	**67**	29	17	12	8
Typhoid fever	..	..	..	..	..	..	..	..	..	..	..	..	34	35	34	28	35	35	**48**	44	43	24

From this it cannot be doubted, keeping in mind the foregoing instances and similar cases elsewhere (e.g., at the Tegel waterworks in Berlin, January to March, 1889 [account already quoted from "Jahresbericht für 1892"]), that typhoid fever and gastro-intestinal diseases are to be attributed to a common vehicle which can only be found in the public water-supply (p. 238).

3. Tuberculosis.

Especially surprising was the improvement [as to phthisis] in the period from the fourth to the sixth decade, when the sewerage and water-supply systems just completed must have been of very strong influence for general cleanliness (p. 285).

In tuberculosis the decline in mortality began long before 1872; but this progressive improvement has gone on at a distinctly brisker rate since the middle of the eighth decade, due no doubt to the fact that after the discovery of the tubercle bacillus the measures already in operation were more systematically applied. At the same time it is worthy of notice that it is maintained from the surgical side that since the filtration of the water the number of cases of bone and joint tuberculosis has diminished extraordinarily. Further observations should tell whether a causal connection really exists here. At any rate such a possibility cannot be excluded, since of course the sputa and bowel discharges of all the tuberculous reach the Elbe through the sewers, and tubercle bacilli just as well as typhoid bacilli could have been carried thence in the water to the people (p. 309).

4. Other Infectious Diseases.

In reference to "Inflammatory Diseases of the Respiratory Organs" ("Entzündliche Erkrankungen der Atmungsorgane") (not including phthisis):

Unfortunately such a variety of diseases must be included under this title that only a very general orientation is possible (p. 101).

The decline in these diseases since 1893 is very striking. Prior to that time the annual death-rate from these causes was 3 to 4 per thousand inhabitants, but now the mortality has dropped to 2 to 3 per thousand. What has worked this revolution is difficult to determine, as the picture of events [see diagram] is much confused by the large influenza epidemics of 1891, 1895, and 1900 (p. 103).

The conditions with respect to diseases of the respiratory organs (exclusive of tuberculosis) are even more obscure [than for tuberculosis]. Still the striking improvement [shown by comparative rates for the two periods 1872–96 and 1896–1900] in this group, which includes very diverse forms of disease, must be accredited more to general sanitary improvements than to the filtration of the water (p. 310).

It is interesting to note that of all deaths from inflammatory diseases of the respiratory organs in the period 1872–1900, about 25 per cent occurred among infants under one year of age (pp. 133, 160).

In the quotations here given we believe that we have cited all of special interest or importance in reference to the effect of a purified water-supply upon the various infectious diseases in Hamburg. And we desire, on leaving this portion of the subject, to express our high appreciation of the thoroughness of the work of Dr. Reincke and his associates, which has thrown so much light upon this important subject.

VI. MR. MILLS'S FURTHER STUDIES ON THE WATER-SUPPLY AND TOTAL DEATH-RATE, ETC., OF LAWRENCE, MASSACHUSETTS, AND HIS ADDRESS TO THE CITY GOVERNMENT OF LAWRENCE, 1893–1902.

Ever since 1893 Mr. Mills had been making further observations and studies, some of which he had reported to his colleagues on the State Board of Health of Massachusetts as early as 1896. Several years later (July 3, 1902) in the course of an address before the city government of Lawrence, he read a statement of his results, from which we may quote the following striking paragraphs, published the next day in the Lawrence newspapers:

> The deaths from typhoid fever dropped from an average of 52 per year for the six years previous to the use of the filtered water to an average of 12 per year in the past six years. But this is only a small part of what has been accomplished. The deaths from all diseases in the city have, since the filter was built, averaged 19 annually per thousand of inhabitants, while in the six years previous to the building of the filter the deaths from all diseases averaged 24 per 1,000 annually. That is, in the years since you began to use filtered water there has been an average of 300 less deaths per year than there would have been if the death-rate had continued as before. . . .
>
> When the United States Census Bureau of 1900 found that the deaths in Lawrence were, when they considered the increase in population, equivalent to more than 300 less deaths than in 1890, they wrote to your City Board of Health asking the cause, and were informed that the principal cause that they could indicate was the introduction of filtered water for the use of the city in 1893. They had reason for their conclusion when their records showed the deaths in 1892 to be 1,246 and the deaths of 1894 to be 925; a difference of 321 deaths from the year before to the year after the filter was completed.
>
> Since you began to drink filtered water the records show that there have been as many as 2,500 less deaths in the city than there would have been if the average death-rate of the previous six years had continued to this time; and this has been one of the sources of increase in population. . . .
>
> The decrease in deaths has not been limited to deaths caused by diseases which are known to be conveyed by water, nor to infectious diseases, but includes so broad a range of diseases that we must conclude that the general health of the people has been improved and their ability to resist and overcome disease has increased.

VII. DISCUSSION BY MR. ALLEN HAZEN, C.E., OF THE WATER-SUPPLY OF LAWRENCE IN RELATION TO THE TOTAL DEATH-RATE, 1901.

In the published discussion of a paper[1] presented by Messrs. Morris Knowles and C. G. Hyde at a meeting of the American Society of Civil Engineers, June 5, 1901, Mr. Hazen made the following statement:

> While the most striking reduction in the death-rate following the use of filtered water was in typhoid fever, the general death-rate showed a very considerable reduction. Table No. 26 shows the death-rate per thousand living for the seven years that the filter has been in operation, together with the corresponding rates for three preceding periods of seven years each.
>
> The reduction in the general death-rate in the last seven years, as compared with the seven preceding years, is several times as large as the reduction in the typhoid

---

[1] The Lawrence, Mass., City Filter: A History of Its Installation and Maintenance, *Trans. Am. Soc. C.E.*, 46, p. 316.

> fever death-rate, and perhaps indicates the effect of the quality of the water on other diseases. The question as to how far this is due to the water-supply, and how far to improved general sanitary conditions, may be properly raised; but the very decided reduction at the time of the introduction of the filter, and the steadiness with which the rate has continued on a lower level since, seem to indicate that the water-supply had something to do with the reduction, and that the coincidence was not accidental.

VIII. A GRAPHICAL DEMONSTRATION OF THE LAWRENCE PHENOMENA PUBLISHED BY MR. MILLS, 1904.

In April, 1904, Mr. Mills showed to one of the authors (W. T. S.), who was about to give in Lawrence a public address on the water-supply of that city, the diagram herewith reproduced (with addition of recent years by the authors) as Chart 1, and kindly permitted him to make from it a lantern slide which he then used and has since used from time to time in his lectures. This diagram, which was afterward published with slight additions in the Annual Report of the Water Board of Lawrence for 1906, illustrates in a very striking way the Mills-Reincke phenomenon to which we have now repeatedly referred.

IX. FORMULATION OF HAZEN'S THEOREM, 1904.

At the International Engineering Congress held at St. Louis in October of the same year, Mr. Allen Hazen took an important step in advance, and formulated a numerical expression for the comparative effect of water purification upon typhoid fever mortality and total mortality. He had already approximated such an expression in his statement made in 1901 and quoted above that—

> the reduction in the general death-rate . . . . is several times as large as the reduction in the typhoid fever death-rate.

On account of its importance as the first attempt, so far as we are aware, to reduce to a quantitative statement the Mills-Reincke phenomenon, we shall quote in detail that part of Mr. Hazen's study which concluded with the formulation as above mentioned of a numerical expression of the relation of total mortality to typhoid fever mortality.

> The general death-rate, as might be expected, is also reduced, and it is reduced to a greater extent than can be accounted for in the reduction of the typhoid fever rate. The percentage of reduction in the general death-rate is less than it is with typhoid

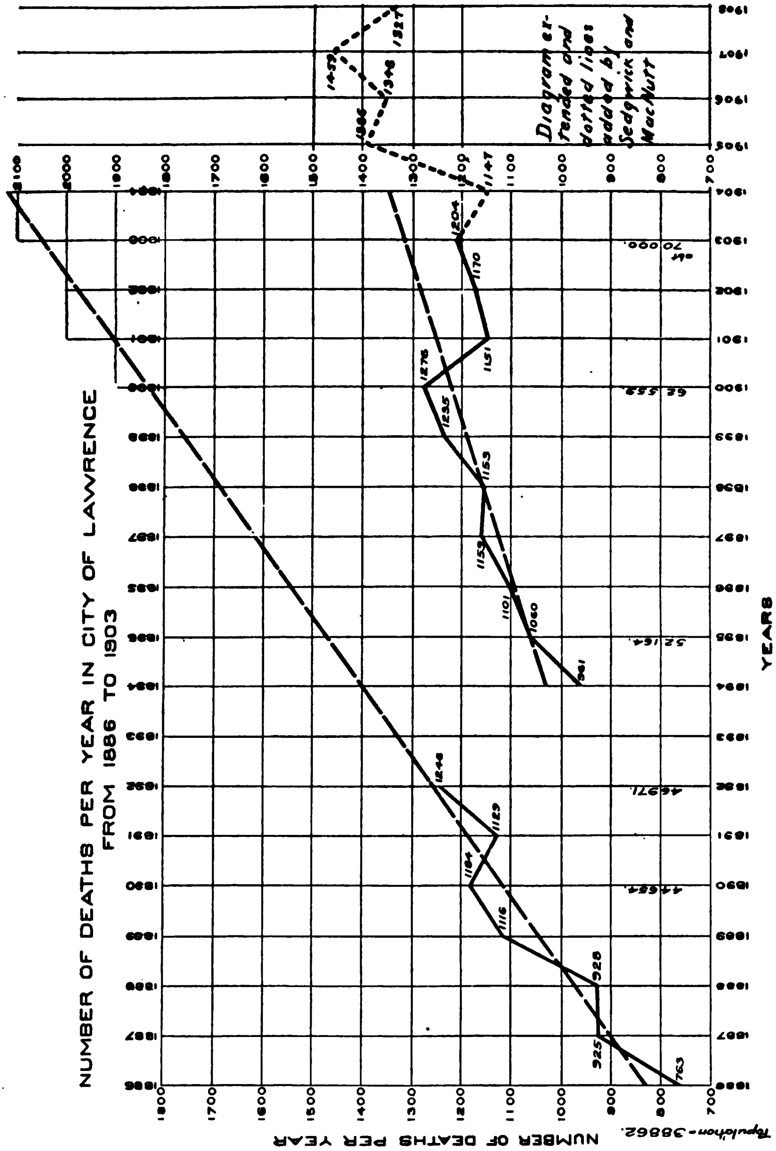
NUMBER OF DEATHS PER YEAR IN CITY OF LAWRENCE
FROM 1886 TO 1903
NUMBER OF DEATHS PER YEAR
YEARS
Population - 38862.
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
763
925
928
1116
1184
1129
1248
981
1060
1101
1153
1153
1235
1276
1151
1170
1204
1147
1386
1459
1348
1327
44654.
46971.
52164.
62559
70000. est.
Diagram extended and dotted lines added by Sedgwick and MacNutt

Chart 1.

fever and it is therefore more difficult to follow the relation, and the reduction attributable to the change in water can be ascertained with less certainty.

Tables 5 and 6 show the general death-rates and the death-rates from typhoid fever in a number of cities, before and after radical improvements in their water-supplies. In four cases, two in Europe and two in the United States, the changes were made by the installation of sand filters. In the other cases the changes were from polluted river supplies to upland waters from unpolluted sources, or to ground-water. The year of change (when both the old and new supplies were in use) is omitted in each case. At Lowell, Mass., where the change was more gradual, two years are omitted, and at Hamburg, the cholera year, 1892, which immediately preceded the year in which the filters were put in service, is also omitted from the comparison.

TABLE 5.

DEATHS FROM TYPHOID FEVER PER 100,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Zurich, Switzerland............... Filtration	1885	76	10	87
Hamburg, Germany............... Filtration	1892–93	47	7	85
Lawrence, Mass................. Filtration	1893	121	26	79
Albany, N.Y.................... Filtration	1899	104	28*	73
Lowell, Mass., river water to ground-water.....	1895–96	97	21	78
Newark, N.J., river water to upland water.....	1892	70	16	77
Jersey City, N.J., river water to upland water..	1896	77	24	69
Averages..............................		85	19	78

* Four years.

The reductions in death-rates with the installation of filters have been quite as great as in those cities where the new sources of supply were from unpolluted sources. The average reduction in the typhoid rate was 66 per 100,000. The reduction in the general death-rate was 4.7 per 1,000 or 470 per 100,000.

TABLE 6.

DEATHS FROM ALL CAUSES PER 1,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Hamburg, Germany............... Filtration	1892–93	24.0	17.7	26
Lawrence, Mass................. Filtration	1893	24.4	20.0	18
Albany, N.Y.................... Filtration	1899	22.3	18.4*	17
Newark, N.J., river water to upland water.....	1892	25.1	22.1	12
Jersey City, N.J., river water to upland water..	1896	25.4	19.3	24
Lowell, Mass., river water to ground-water.....	1895–96	25.1	20.5	18
Averages..............................		24.4	19.7	19

* Four years.

While the reduction in the typhoid rate is 66 per 100,000, that in the general death-rate is 4.7 per 1,000 or 470 per 100,000, or seven times as much. Where there is one less death from typhoid fever there are six less from other causes.

The writer believes that the whole of the reduction in the typhoid rate should be attributed to the change in water-supply, because cities similarly situated, which have

> not improved their supplies, have experienced no permanent reduction in their typhoid fever rates. With the general death-rate the case is different. Improved general sanitary conditions have reduced the death-rates in recent years, and the normal reduction in a period of six years, which represents the average elapsed time between the first and second series of results, would account for a part of the reduction in the general death-rate.
>
> The average reduction in the general death-rate between 1890 and 1900 in eighteen cities having from 50,000 to 300,000 inhabitants, in New England, New York, and New Jersey, which made no radical change in their water-supplies, was 2.28 per 1,000. This is computed from the Report on Vital Statistics in the United States Census of 1900. Assuming a uniform decrease in rate in the interval, the average, or what we may call the normal, reduction, in 6 years would have been 0.6 of this, or 1.37 per 1,000. In comparison with this, in five cities where the water was radically improved, the reduction in the same period was 4.4 per 1,000. The results may be tabulated as follows:

	Death-Rate per 100,000 Living
Reduction in total death-rate in five cities with the introduction of a pure water-supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated but with no radical change in water-supply	137
Difference, being decrease in death-rate attributable to change in water-supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water-supply	232

> This computation indicates that *where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.* [Italics our own.] This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water-supply, used freely and with confidence, results in a better general tone in the systems of the population, and so indirectly to a lower death-rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water-supply ("Trans. Am. Soc. C.E.," 54D pp. 151–53).

The quantitative relation thus arrived at by Mr. Hazen and italicized above, seems to us to deserve, because of its far-reaching importance, some special designation. We have therefore ventured to apply to it in our preliminary paper[1] the term *Hazen's Theorem.*

Mr. Hazen further added, in the discussion on this paper:

> The writer agrees with Messrs. [E. O.] Jordan and G. W. Fuller that it is most important that further study be made of the effect of water-supply upon other diseases than typhoid fever. The statistics certainly indicate a much wider influence of water-supply upon public health than has been generally admitted; and it would seem as if studies might be made to ascertain the facts more definitely (*ibid.*, p. 251).

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[1] *Science*, August 14, 1908.

X. OTHER DATA AND DISCUSSIONS BEARING ON THE GENERAL SUBJECT.

We have not been able to find later than the formulation in 1904 of Hazen's theorem any definite advance in the analysis of the underlying Mills-Reincke phenomenon or any attempt at a general proving of the theorem itself. It enunciation has, however, caused occasional discussion and called forth some confirmatory data from various quarters. Without attempting to quote all such data and discussions we shall summarize the more important.

Professor Edwin O. Jordan, in the discussion on Mr. Hazen's St. Louis paper, made the following remarks:

> Mr. Hazen's computation which indicates that, in addition to the reduction in deaths from typhoid fever, there occurs a similar reduction in deaths from other causes, and that this also is attributable to a change in the water-supply, is certainly very striking. There is one suggestion which the writer would like to offer concerning a possible explanation of this circumstance.
>
> It is well known that the obscure character and variable symptoms of certain cases of typhoid fever lead not uncommonly to a mistaken diagnosis. There is no doubt that in every considerable body of vital statistics some cases of genuine typhoid fever are reported under other names. It need hardly be said that this is particularly true as regards the deaths reported under the captions "typho-malarial fever," "malarial fever," and similar designations. In the Northern United States, the majority of the deaths reported under these headings are deaths from typhoid fever. The effect of filtration well illustrates this point. In the city of Albany, N.Y., there were 37 deaths reported under the heading "malarial diseases" in the four years, 1891–94, and 23 deaths in the four years, 1895–98, while for the four years following filtration (1900–1903), there were but two deaths under the same head.
>
> It must be remembered also that a marked improvement in methods of diagnosis of typhoid fever has taken place during the last decade. One result of this has been that deaths formerly reported as occurring from other causes are now correctly reported as due to typhoid fever. This transfer to the column of typhoid deaths naturally diminishes the deaths reported from general causes and must, at least, partly explain the relation pointed out by Mr. Hazen. It may also serve to explain why the apparent reduction in deaths from typhoid fever is sometimes less than would be reasonably anticipated. The suggestive facts brought out in the paper indicate that other items under the reported deaths in official health reports might repay examination ("Trans. Am. Soc. C.E.," 54D, pp. 206, 207).

Three years later the phenomenon observed at Lawrence by Mr. Mills was referred to in a paper[1] by Mr. H. W. Clark, who called attention to a similar decline following the introduction of filtration at Albany, N.Y.

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[1] *Monthly Bull. Mass. State Board of Health*, Sept., 1907, p. 242.

On November 6, 1907, Mr. Edward E. Wall, in a paper[1] presented before the American Society of Civil Engineers, wrote as follows:

> Allen Hazen, M. Am. Soc. C.E., estimates that where one death from typhoid has been avoided through an improved water-supply probably two or three deaths from other diseases have been avoided. The following record seems to indicate a higher proportion of decrease than Mr. Hazen's estimate would give:

ANNUAL MORTALITY RECORD, ST. LOUIS, MO., 1900–1906, FROM DISEASE ALONE.
[Chemical precipitation introduced in 1904.]

1900	9,217	1904	10,695
1901	9,916	1905	9,545
1902	9,654	1906	9,214
1903	10,320		

Mr. Mills's observation of the phenomenon at Lawrence was again referred to by Mr. Stephen DeM. Gage in the discussion on a paper on filter operations at Lawrence, Mass., presented by Messrs. M. Knowles, M. F. Collins, and A. D. Marble before the New England Water Works Association, February 12, 1908:

> In addition a very material reduction has occurred in the total death-rate of the city, a reduction so different in character from that gradual decrease due to increased appreciation of municipal sanitation which has taken place throughout the State of Massachusetts and following so closely the introduction of filtered water that it can only be explained by attributing it to the improvement in water-supply ("Jour. N.E. Water Works Assn.," 22, p. 232).

Mr. Gage accompanied his statements with a diagram showing the decline in the typhoid fever death-rate and in the total death-rate at Lawrence for the period 1880–1905.

Finally, as the only other reference we have been able to discover, we may record the observation based on statistics, by Mr. E. L. Grimes, City Engineer of Troy, N.Y., and reported at the same meeting, that following the extension and sanitary improvement of the water-supply of that city there occurred a distinct decrease, not only in the deaths from typhoid fever, but also in the deaths from cholera infantum, diarrhea, diseases of the digestive organs, and of children under five years of age.[2]

XI. A RECAPITULATION OF THE LITERATURE, AND A BRIEF OUTLINE OF THE WORK OF THE AUTHORS.

A review of the foregoing sections leads irresistibly to the conclusion that Messrs. Mills, Reincke, and Hazen, in their observations and studies already described, have brought to light phenomena of the very first importance in sanitary science. There appears to be no escape from the conclusion that the purification of polluted public water-supplies reduces the general death-rate much more than it would be reduced by the saving of deaths from the commonly recognized water-borne diseases, typhoid fever and Asiatic cholera, alone. The question naturally arises, to what extent is the general death-rate reduced? And this simple question Hazen's theorem undertakes to answer. Another question which naturally arises is, in what particular diseases does this reduction take place? And this question we shall ourselves undertake to answer.

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[1] "Water Purification at St. Louis, Mo.," *Trans. Am. Soc. C.E.*, 60, p. 182,

[2] *Jour. N.E. Water Works Assn.*, 22, p. 183.

As yet very few students of public health science are aware of the extent of the studies of Reincke and Mills; and no one, so far as we know, has hitherto undertaken any thorough confirmation of their results. We have therefore ventured to make a study of this kind, first critically examining all the evidence in our possession relating to the Mills-Reincke phenomenon and Hazen's theorem; and then, having found the latter sound and conservative, passing on to the study of fresh examples, to test its scope and range.

Following the historical development of the subject we have naturally begun with the data afforded by the city of Hamburg.

XII. A GRAPHICAL DEMONSTRATION AND DISCUSSION, BY THE AUTHORS, OF THE HAMBURG PHENOMENA.

As a detailed demonstration of the mortality phenomena before and after the introduction of filtration at Hamburg we have taken statistics from the "Sanitary History of Hamburg in the Nineteenth Century" and plotted from them in Chart 2 the curves for certain important causes of death. On the vertical lines, corresponding to the middle of each year, are plotted the average annual death-rates. The period of unfiltered water is indicated by the heavy black bars beginning on the left and crossing more than one-half the diagram. The period of filtered water-supply is indicated by the clear spaces following these heavy black bars. The scale employed, it must be observed, is the same for all the curves except the two lowest, thus facilitating comparisons. In order to save space, the unused portion of the scale below each curve except the uppermost has been cut off.

Hamburg is well known in the annals of sanitary science on account of its great Asiatic cholera epidemic of 1892. A slow sand filter was at that time in process of construction, and the epidemic of cholera caused a precipitate activity in construction which resulted in the rapid completion of the filter and the beginning of its operation in May, 1893. A brief description of the water-supplies of Hamburg and the neighboring city of Altona is given by Dr. Reincke in his Annual Report for 1892 and translated by Mr. Hazen in an appendix to his "Filtration of Public Water-Supplies." A fuller account is given in the "Sanitary History of Hamburg in the Nineteenth Century." We need only recall that previous to the introduction of filtration in Hamburg the public water-supply was taken from the (tidal) Elbe River at a point about four miles above the outfalls of the main trunk sewers of Hamburg and Altona. In 1893 the intake was moved about a mile farther upstream, and while the river at these points was probably not ordinarily heavily polluted, Dr. Reincke brings conclusive evidence (quoted by us, pp. 495–97, 500–503) to show that at certain times of high tide and low river the sewage of Hamburg and Altona was driven upstream and came at such times directly to both intake points. By filtration the effects of the pollution from this source have been eliminated. As the diagrams of death-rates in Chart 2 speak for themselves, we need comment on them only briefly.

From the first curve it will be seen that the typhoid fever death-rate fell from an average of about 30 in the five years prior to 1893 to a rate after filtration of less than 10 per 100,000.

In inflammatory diseases of the respiratory organs there was an extraordinary drop, and the rates from this cause of death have continued on a much lower level since 1893. The fall in the mortality from these diseases is so striking that we have continued the computation of the rates for a few years beyond the last date shown in the plate, and have found that the low level assumed after introduction of filtration was steadily maintained. The following rates are computed from data from the Imperial Health Office Bulletin, "Sterbefälle im Deutschen Reiche"; for 1901, 228; 1902, 215; 1903, 196; 1904, 188; and may readily be added by the reader if he so desires. (To avoid misunderstanding of the method of plotting

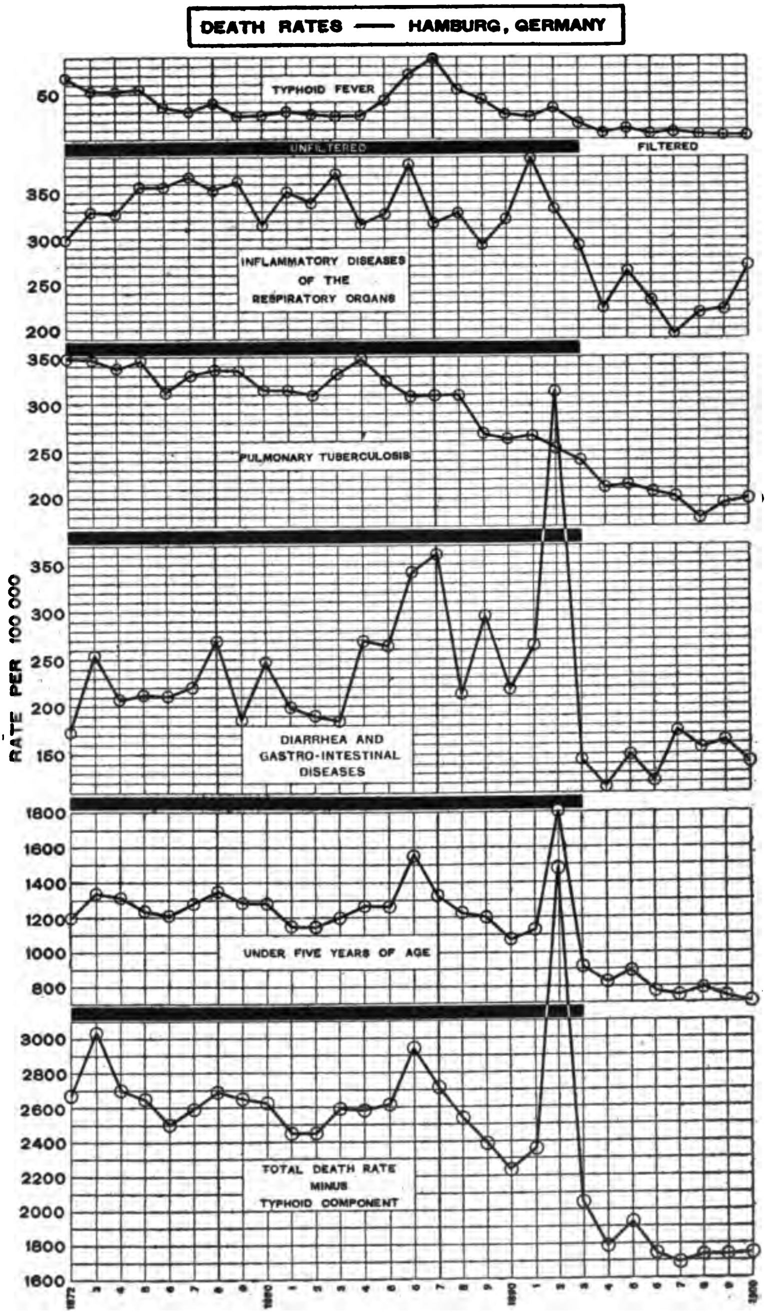
DEATH RATES —— HAMBURG, GERMANY
TYPHOID FEVER
50
UNFILTERED
FILTERED
INFLAMMATORY DISEASES OF THE RESPIRATORY ORGANS
350
300
250
200
PULMONARY TUBERCULOSIS
350
300
250
200
DIARRHEA AND GASTRO-INTESTINAL DISEASES
350
300
250
200
150
UNDER FIVE YEARS OF AGE
1800
1600
1400
1200
1000
800
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
3000
2800
2600
2400
2200
2000
1800
1600
RATE PER 100 000
1872
3
4
5
6
7
8
9
1880
1
2
3
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900

CHART 2.

we must again caution the reader that the unused scale below this, as below subsequent curves, has been cut off.)

Pulmonary tuberculosis, which had been gradually declining for ten years, showed a somewhat greater rate of decline for the year following the introduction of filtration. Whether the purification of the water-supply played any considerable part in this we are unable, from the Hamburg data alone, to determine, but our studies in later sections of this paper on Lawrence and Lowell, Massachusetts, give good reason for supposing that at Hamburg also the purification of the water-supply had a certain effect in lowering the mortality from phthisis.

The title "diarrhea and gastro-intestinal diseases," as used in Chart 2, corresponds to the German *Durchfall und Brechdurchfall.*[1] The curve for this cause of death shows very strikingly the influence of the change to a purified water-supply. From an average rate immediately before filtration of about 300 it dropped suddenly by a full half, at which level it has since continued to 1900. We are forcibly reminded of Dr. Reincke's remark, already quoted, that "in no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these."

The curve for the death-rate of children under five years of age shows a similarity to that for diarrhea and gastro-intestinal diseases, including as it does a large number of deaths from the latter. Thus the drop in 1894 and the continued lower level of subsequent years is seen in a degree which, when the difference of the scales is taken into account, is as striking here as in the curve just above. A considerable share of this mortality is also contributed by inflammatory diseases of the respiratory organs, and a certain similarity between the two curves may readily be traced. We again call attention to the fact that the scale in this diagram, like all the others in the chart except the topmost, is not extended fully to the true base line.

Finally, the diagram for total death-rate minus typhoid component illustrates strikingly that drop following the introduction of filtration which we have named the Mills-Reincke phenomenon, as observed at Hamburg by Reincke. It is at once seen how sudden, how great, and how permanent was the reduction in this death-rate.

---

[1] See note, p. 494.

The rate had reached a miminum in 1900, and was on its way up again when the influence of filtration came into play. How great numerically the reduction actually was, and how far it is to be attributed to the purification of the water-supply, is discussed below.

In order to carry the graphical demonstration still farther, we have plotted in Chart 3 the death-rates for age-groups, which rates are reckoned more accurately—on the population in each age-group—than on the total population. The Mills-Reincke phenomenon is here seen to affect all age-groups—that under one year, however, most notably. This is evidently to be accounted for very largely by the relation of water-supply to diarrheal and gastro-intestinal diseases, as explained by Dr. Reincke (secs. iv and v), 90 per cent of these diseases having occurred among infants under one year of age and constituting about one-quarter of the whole mortality of the latter.

Thus from Charts 2 and 3 it is seen that all of Dr. Reincke's statements on the decline in total death-rate, in infant mortality, and in the other diseases mentioned by him are fully substantiated. More than that, the data afford a basis for going somewhat beyond his statements, which, as we shall show, were characterized by much caution.

It may be objected that there were, possibly, at the time under consideration, declines in the total death-rates of German cities in general; in order, therefore, to show the extraordinary character of the drop at Hamburg we present the table on p. 519 for the ten largest cities of Germany (according to the Census of 1890), showing their average total death-rates for two periods of three years each, before and after the cholera years and introduction of filtration at Hamburg, the corresponding typhoid fever rates also being given.

It is at once evident how remarkable the reductions were at Hamburg, both in typhoid fever and in the total death-rate. Taking the typhoid fever rate as an index of quality of water-supply, Hamburg is shown to have been much worse off than any other city during the first period. In the second period all show declines, but that in Hamburg stands far above them all, having been six times as great as the average

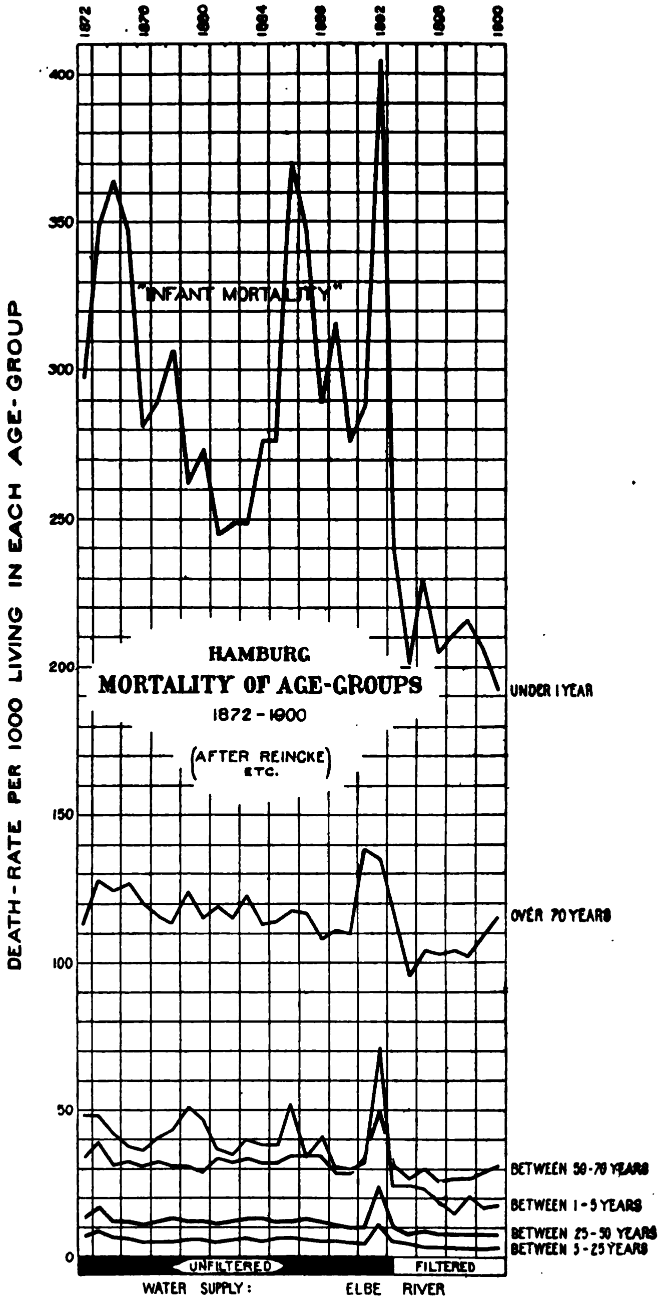
HAMBURG
MORTALITY OF AGE-GROUPS
1872 - 1900
(AFTER REINCKE ETC.)
"INFANT MORTALITY"
DEATH-RATE PER 1000 LIVING IN EACH AGE-GROUP
1872
1876
1880
1884
1888
1892
1896
1900
400
350
300
250
200
150
100
50
0
UNDER 1 YEAR
OVER 70 YEARS
BETWEEN 50-70 YEARS
BETWEEN 1-5 YEARS
BETWEEN 25-50 YEARS
BETWEEN 5-25 YEARS
UNFILTERED
FILTERED
WATER SUPPLY: ELBE RIVER

CHART 3.

for the other nine cities. In total death-rate the drop at Hamburg is much greater than that of any other city, and over four times as great as that of the other nine, and this over and above the results of sanitary improvements going on in the other cities.

TABLE 4.

TEN LARGEST GERMAN CITIES	TYPHOID FEVER DEATH-RATES PER 100,000			TOTAL DEATH-RATES PER 1,000		
	1889–91 incl.	1894–96 incl.	Decrease	1889–91 incl.	1894–96 incl.	Decrease
1. Berlin	13	5	8	21.8	20.0	1.8
2. **Hamburg**	**31**	**7**	**24**	**23.1**	**19.2**	**3.9**
3. Munich	8	3	5	27.6	25.2	2.4
4. Breslau	12	8	4	28.8	27.3	1.5
5. Leipzig	13	9	4	20.0	21.7	−1.7
6. Cologne	13	7	6	25.8	24.1	1.7
7. Dresden	8	6	2	20.8	21.0	−0.2
8. Magdeburg	20	9	11	24.6	23.7	0.9
9. Frankfort-on-the Main	8	5	3	18.9	17.6	1.3
10. Hanover	8	7	1	19.6	19.3	0.3
Nine cities exclusive of Hamburg (average)	11	7	4	23.1	22.2	0.9

Typhoid fever death-rates, with exception of Magdeburg, from G. C. Whipple's "Typhoid Fever," App. XVI; other death-rates computed from "Statistisches Handbuch deutscher Städte." The Hamburg figures refer to the *Stadt* exclusive of suburbs, and hence do not quite agree with the rates given by Dr. Reincke for the whole Hamburg district (*Staat*).

Several questions naturally arise at this point. How great was the reduction at Hamburg, not only in the total death-rate, but also in the specific diseases? And what causes contributed most to the total reduction? In answer to these questions we submit in the table on p. 520 a statistical synopsis which we have made of the Hamburg phenomena. The cholera year (1892) and year of introduction of filtration (1893) are omitted, and the means of five years before and five years after are computed, so as to be comparable with our studies of Lawrence and Lowell in sec. xvi.

Of the total reduction, i.e., in the general death-rate, we find that the chief components for specific causes of death are as follows: 19 per cent contributed by diarrhea and gastro-intestinal diseases; 15 per cent by inflammatory diseases of the respiratory organs; 12 per cent by phthisis; 8 per cent by diphtheria; 6 per cent by typhoid fever; and 40 per cent by other causes of death. Viewing the total reduction from the standpoint of age of decedents, we find that 38 per cent falls in the infant mortality under one year of age (as reckoned on the total population).

For every death less from typhoid fever after filtration there were 15.8 deaths less from other causes, but as this figure is merely crude—i.e., has not been corrected for the decrease in mortality that would have taken place independently of water-supply purification—it cannot properly be substituted as the numerical member of Hazen's theorem (see p. 510). It is, however, so much greater than the figure suggested by Mr. Hazen that we are led to venture a partial explanation in the fact that there was not as much typhoid fever to begin with at Hamburg as at Lawrence and Lowell, whether the periods before or after filtration be compared; so that typhoid fever played a smaller part, in proportion, at Hamburg, than in the two American cities upon which, among others, Mr. Hazen's estimate was based.

TABLE 5.

DEATH-RATES, GENERAL AND SPECIFIC, IN HAMBURG BEFORE AND AFTER ADOPTION OF FILTRATION. Computed from the "Sanitary History of Hamburg in the Nineteenth Century."

Cause of Death	Mean Death-Rate 1887–91 Incl.*	Mean Death-Rate 1894–98 Incl.*	Percentage Decrease
All causes	2444	1,774	27
Asiatic cholera	No deaths	except in 1892 and	1893
Typhoid fever	47	7	85
†Diarrhea and gastro-intestinal diseases	270	143	47
†Infant mortality (under 1 year)	304	213	30
Inflammatory diseases of the respiratory organs	329	226	31
Phthisis	283	202	29

* Rates are per 100,000 of population except in the case of infant mortality, for which they are reckoned per 1,000 living under one year of age.

† These two titles overlap; one-quarter of the "infant mortality" is due to "diarrhea," and nine-tenths of the deaths from the latter fall under "infant mortality."

To sum up the Hamburg phenomena, we return again to the striking demonstration of the Mills-Reincke phenomenon as observed there by Dr. Reincke. This consisted in a sudden and permanent drop in the total death-rate minus typhoid component in 1893, an effect observable even in the rate for that year. The whole trend since 1872 of all the curves which we have exhibited, with the exception of that for pulmonary tuberculosis, was changed, each one pitching rapidly and immediately downward and assuming a distinctly lower level thereafter. We refer again to Dr. Reincke's comments on these phenomena as summarized in the preceding pages. We may here anticipate, and say that after our studies on other cities set forth in the following sections, we shall be forced to conclude that—except in respect to diarrhea and gastro-intestinal diseases and the recognized water-borne diseases, typhoid fever and Asiatic cholera—Dr. Reincke attributed to the purification of the public water-supply much less than its true share in the remarkable reduction in the total and specific death-rates of Hamburg.

XIII. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LAWRENCE PHENOMENA

We have made a careful study of the vital statistics of the city of Lawrence, where the Mills-Reincke phenomenon was first observed by Mr. Mills, following the introduction of filtration in 1893. In addition to Lawrence we have taken Lowell, Mass., where the public water-supply was also purified about the same time by a different method, i.e., substitution of unpolluted ground-water for polluted river water. Finally, we have taken the city of Manchester, N.H., as being in every important respect similar (as we shall show) to the two cities just mentioned and therefore an excellent norm for comparison. For all of these cities accurate vital statistics are fortunately obtainable. We have based our computations upon substantial foundations, viz., the populations given by the U.S. Census for 1880, 1890, and 1900, and the Massachusetts State Census for 1885, 1895, and 1905, computing the populations for the intermediate years by the "arithmetical" method of the U.S. Census.[1] The possibility of important errors arising from this method of computing populations for intercensal years will be discussed in section xviii.

The cities of Lawrence, Lowell, and Manchester, all manufacturing cities devoted chiefly to textile industries, are situated in the valley of the Merrimac River, a large, swift stream draining a considerable portion of southern New Hampshire and northern Massachusetts. The first two cities are especially well known through the studies on typhoid fever made there by the Massachusetts State Board of Health, and published in the Report of the Board for 1892. The three cities are so similar in size, character of population, industry, and climatic conditions, that they are particularly favorable for purposes of sanitary comparison. Three cities more similar in almost every respect could hardly be found elsewhere. In one important particular, however, they have differed—viz., in their water-supplies—and, as we shall see below, this fact, in connection with their close similarity in other respects makes their experience almost equivalent to a laboratory experiment. Lawrence, previous to 1893, had taken its water-supply directly from the polluted Merrimac River only nine miles below the sewers of Lowell, but introduced in that year slow sand filtration; Lowell changed in the years 1894 and 1895 from the same polluted river to a pure ground-water; while Manchester had, throughout the period which we shall consider a surface-water supply of good quality.

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[1] The merit of this method as compared with certain others in vogue is discussed in Twelfth Census, *Bull. No. 135*, "Methods of Estimating Population."

TABLE 6.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†39,151												
1883	38,978	850	28	60	9	147	57						
1884	38,919	892	19	68	13	142	73						
1885	†38,862	774	17	67	17	163	44						
1886	40,020	763	23	45	14	125	55						
1887	41,178	925	47	74	17	132	71						
1888	42,337	928	48	95	16	134	77	11	17	42	54	29	13
1889	43,495	1,116	55	75	10	110	96	170	23	52	65	17	14
1890	†44,654	1,184	60	117	28	114	96	78	19	74	58	14	20
1891	46,156	1,129	55	133	30	91	101	50	34	69	61	13	24
1892	47,658	1,246	50	156	27	95	130	28	30	94	43	20	10
Change: 1893	49,160	1,184	39	161	15	113	102	23	29	65	38	23	21
Water-supply, filtered:													
1894	50,662	961	25	88	17	88	101	16	34	56	46	23	17
1895	†52,164	1,060	18	109	23	113	100	14	29	Not given			
1896	54,243	1,101	14	127	32	105	103	25	40	47	62	20	20
1897	56,322	1,159	14	138	26	93	124	47	27	52	73	19	19
1898	58,401	1,153	14	86	30	101	119	63	39	64	82	18	22
1899	60,480	1,235	21	119	36	123	111	64	35	87	87	19	25
1900	†62,559	1,276	13	138	43	116	147	35	34	48	102	19	37
1901	64,057	1,151	13	126	34	108	‡	17	40	44	103	12	23
1902	65,555	1,170	15	169	47	107	‡	12	49	32	87	8	21
1903	67,054	1,226	23	127	36	117	‡						
1904	68,552	1,147	11	159	31	111	‡						
1905	†70,050	1,386	15	203	39	107	‡						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lawrence Board of Health. For certain of the less important causes only the period 1888–1902 inclusive has been taken, the spaces for the remaining years being left blank. Total deaths in this and subsequent Tables 9 and 12 are exclusive of stillbirths.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports.

The statistics for Lawrence for the period which we have studied are given in Tables 6 and 7.

From these figures we have plotted upon diagrams shown in Chart 4 the death-rates from various causes in Lawrence from 1883–1895 inclusive—a period, that is to say, including the year of the sudden change from an unfiltered to a filtered water-supply, and covering the 10 years before, and 12 years after, that event.

TABLE 7.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,181	72	154	23	377	146						
1884	2,292	49	175	33	365	188						
1885	1,992	44	172	44	419	113						
1886	1,907	58	112	35	312	137						
1887	2,246	114	180	41	320	172						
1888	2,192	113	224	38	317	182	26	40	99	128	69	31
1889	2,566	126	172	23	253	221	391	53	120	149	39	32
1890	2,652	134	262	63	255	215	175	43	166	130	31	45
1891	2,444	119	288	65	197	219	108	74	149	132	28	52
1892	2,614	105	327	57	199	273	59	63	197	90	42	21
Change: 1893	2,408	79	328	31	230	208	47	59	132	77	47	43
Water-supply filtered:												
1894	1,897	49	174	34	174	199	32	67	111	91	45	34
1895	2,032	35	209	44	217	192	27	56	...	...	..	..
1896	2,030	26	234	59	194	190	46	74	87	114	37	37
1897	2,058	25	245	46	165	220	84	48	92	130	34	34
1898	1,974	24	147	51	173	204	108	67	110	141	31	38
1899	2,042	35	197	60	203	184	106	58	144	144	31	41
1900	2,040	21	221	69	185	235	56	54	77	163	30	59
1901	1,797	20	197	53	169	†	27	62	69	161	19	36
1902	1,785	23	258	72	163	†	18	75	49	133	12	32
1903	1,828	34	190	54	175	†						
1904	1,673	16	232	45	162	†						
1905	1,979	21	290	56	153	†						

* Computed from preceding table.

† Title discontinued in reports. Slow sand filter went into operation September, 1893.

The method of plotting is the same as that in the chart for Hamburg, the vertical lines upon which the rates are plotted representing the middle of each year, and the period of the use of unfiltered Merrimac River water being shown by a black bar running to September, 1893, when filtration was introduced. The scale employed is the same for all curves except the lowest; and, in order to save space,

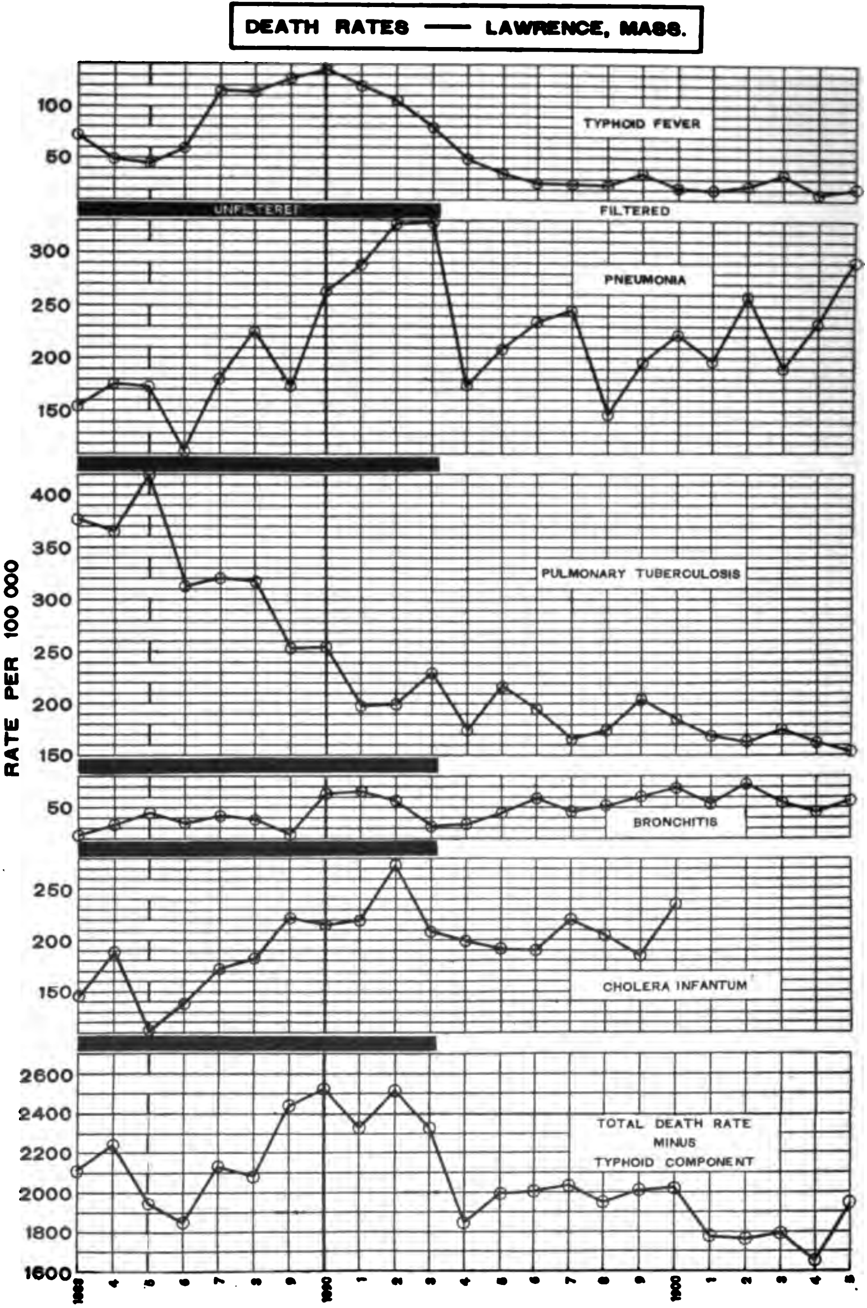
DEATH RATES — LAWRENCE, MASS.
RATE PER 100 000
TYPHOID FEVER
100
50
UNFILTERED
FILTERED
PNEUMONIA
300
250
200
150
PULMONARY TUBERCULOSIS
400
350
300
250
200
150
BRONCHITIS
50
CHOLERA INFANTUM
250
200
150
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
2600
2400
2200
2000
1800
1600
1893
4
5
6
7
8
9
1900
1
2
3
4
5
6
7
8
9
1910
1
2
3
4
5

CHART 4.

the unused portion of the scale below each curve has been cut off, so that no base-lines are shown.

If we now proceed to analyze the different curves, we find that typhoid fever, which reached epidemic proportions of large magnitude in 1890, declined even before the introduction of the filter, as might naturally have been expected; but immediately afterward sank lower than for many years, and has since remained on a comparatively low level.

The curve for pneumonia is particularly interesting and striking, for it shows that this disease previous to 1893 had been rising by leaps and bounds most of the time since 1885, and had reached very large proportions in 1893. With the introduction of a purer water-supply pneumonia immediately fell back to a point lower than it had shown since 1889; and, altho it rose again somewhat, remained on a comparatively low average for the next 10 years.

Pulmonary tuberculosis was falling rapidly prior to the introduction of filtration, and continued to fall, tho more slowly, afterward. Altho in the curve any decline in phthisis consequent on water purification is so obscured by the effect of improvement in all sorts of other sanitary conditions that it cannot be directly demonstrated, nevertheless, as we showed in our paper entitled "An Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis" (referred to above, p. 491), a distinct effect of the filtration of the water-supply appears in this disease also. The evidence upon which this conclusion is based—as will be seen by reference to the above-mentioned paper, or to sec. xvi of the present paper where the same data are presented—is drawn from an analytical comparison with Manchester (*vide supra*) as a norm.

The curve for bronchitis shows no noteworthy phenomena beyond the lowness of the rates for 1893, 1894, and 1895 as compared with the three years next preceding. For this disease also a comparison with some other city such as Manchester as a control is required and is given beyond.

Cholera infantum, which was quite high for several years before the introduction of filtration, was somewhat lower for a number of years afterward.

When we come to the curve at the bottom of the chart we find a striking demonstration of the Mills-Reincke phenomenon. For we see that during the four years previous to the introduction of filtration the total death-rate had been very high, sometimes a little exceeding and sometimes falling a little below 24 per 1,000, a figure of notable height even if all the typhoid fever deaths had been included. Neglecting the year 1893, inasmuch as this was a year characterized partly by polluted and partly by purified water-supply, and beginning with 1894, we observe a most remarkable and extraordinary drop, a drop all the more surprising and convincing since the death-rate here shown is that from diseases and causes of death other than typhoid fever. This curve shows apparently even more clearly than does the typhoid fever curve itself at the top of the chart the striking effect of the purification of the public water-supply.

XIV. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LOWELL PHENOMENA

We now present a graphical demonstration of the phenomena at Lowell, based upon statistics which have the same secure foundation as those for Lawrence.

This city, 28 miles below Manchester, and 12 miles below Nashua, N.H., both the latter cities and several others at greater distances discharging their sewage into the Merrimac River, used the polluted river water without purification until 1893. In that year deep wells were driven and the new water was introduced into the city mains along with the old. The supply of ground-water was gradually increased until 1896, when the river water was entirely shut off. The following table shows the progress of the substitution of pure water for polluted:

TABLE 8.

AVERAGE CONSUMPTION OF RIVER WATER AND OF GROUND-WATER IN LOWELL.*

Year	Total Consumption (Million Gals. per Day)	River Water (Percentage of Total)	Ground-Water (Percentage of Total)
1892	...	100	0
1893	6.8	91	9
1894	6.6	65	35
1895	7.0	33	67
1896	7.0	4	96
1897	...	0	100

---

* Computed from diagram in *Annual Report of Lowell Water Board, for 1896*. The first well water was pumped September 16, 1893. The river water was finally shut off February 22, 1896. Thus 1893 was essentially the last year of the old supply, and 1896 the first year of the new.

The statistics upon which we have based our studies of Lowell are presented in Tables 9 and 10.

TABLE 9.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LOWELL, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†59,475												
1883	62,253	1,432	49	103	35	249	125						
1884	63,179	1,400	41	114	43	206	136						
1885	†64,107	1,329	49	85	26	196	126						
1886	66,824	1,499	50	106	33	191	165						
1887	69,542	1,869	90	168	64	232	157						
1888	72,260	1,763	62	154	61	190	183	107	34	159	102	31	50
1889	74,978	1,897	69	145	73	213	215	101	39	159	141	55	46
1890	†77,696	1,960	125	145	96	214	218	41	42	164	148	66	56
1891	79,030	1,975	78	187	96	222	251	16	44	155	156	61	66
1892	80,364	2,229	77	215	114	231	229	28	51	231	140	56	64
Years of change:													
1893	81,698	2,108	55	217	126	212	286	36	52	216	128	69	54
1894	83,032	1,790	51	137	90	188	221	36	37	146	123	51	47
1895	†84,367	1,869	33	155	78	160	218	52	59	142	154	62	62
1896	86,487	1,922	38	157	86	185	221	46	51	149	153	68	64
Ground-water:													
1897	88,607	1,860	17	170	107	180	177	40	67	133	158	46	46
1898	90,727	1,809	25	165	100	188	185	37	62	115	163	49	91
1899	92,848	1,851	18	197	75	194	179	41	63	112	156	22	54
1900	†94,969	1,850	19	208	86	181	132	27	77	137	190	40	73
1901	94,953	2,041	18	238	67	160	‡	114	72	156	197	40	82
1902	94,937	1,943	17	189	80	154	‡	73	82	172	219	34	77
1903	94,921	1,899	26	191	71	124	‡						
1904	94,905	1,738	18	177	73	126	‡						
1905	†94,889	1,899	17	178	70	148	‡						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lowell Board of Health. Stillbirths are excluded.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank.

From these figures the plots in Chart 5 have been constructed. These show the death-rates from various causes for a number of years, as for Lawrence, before and after the purification of the water-supply, including two U.S. Censuses and three state Censuses. Here, as at Lawrence, we have, therefore, a substantial basis for population statistics. The method of plotting is the same as for Hamburg and Lawrence. The gradual substitution of unpolluted for polluted water is represented by the tapering portion of the black bar. The same scale is used for all curves except the bottommost, and here again the diagrams have been cut off so that no base-lines appear.

TABLE 10.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LOWELL, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,300	79	165	56	400	201						
1884	2,216	65	180	68	326	215						
1885	2,073	76	133	41	306	196						
1886	2,243	75	159	49	286	247						
1887	2,688	129	242	92	334	226						
1888	2,440	86	213	84	263	253	148	47	220	141	43	69
1889	2,530	92	193	97	284	287	135	52	212	188	73	61
1890	2,523	161	187	123	276	280	53	54	211	190	85	72
1891	2,499	99	237	121	281	318	20	56	196	197	77	84
1892	2,774	96	268	142	288	285	35	64	287	174	70	80
Years of change:												
1893	2,580	67	266	154	259	350	44	64	264	157	84	66
1894	2,156	61	165	108	226	266	43	45	176	148	61	57
1895	2,215	39	184	92	190	258	62	70	168	183	73	73
1896	2,222	44	182	99	214	256	53	59	172	177	79	74
Ground-water:												
1897	2,099	19	192	121	203	200	45	76	150	178	52	52
1898	1,994	28	182	110	207	204	41	68	127	180	54	100
1899	1,994	19	212	81	209	193	44	68	121	168	24	58
1900	1,948	20	219	91	191	139	28	81	144	200	42	77
1901	2,150	19	251	71	168	‡	120	76	164	207	42	86
1902	2,047	18	199	84	162	‡	77	86	181	231	36	81
1903	2,001	27†	201	75	131	‡						
1904	1,831	19	187	77	133	‡						
1905	2,001	18	188	74	156	‡						

* Computed from preceding table.

† Epidemic August, 1903, due to check-valve accident.

‡ Title discontinued in reports.

Changed from raw river water to deep wells. First ground-water pumped September, 1893. River water finally shut off February, 1896.

Beginning with the curve for typhoid fever, we find that here, as at Lawrence, the mortality had been subsiding, as was to be expected after the epidemic proportions of 1890; but sank still lower in the years of introduction of ground-water, remaining since at a comparatively low level.

Pneumonia, which had been on the whole rising, distinctly tho irregularly for many years, exhibits the striking phenomenon of an immediate drop from the high point which it had reached in 1893. The comparatively low level to which it now descended was, moreover,

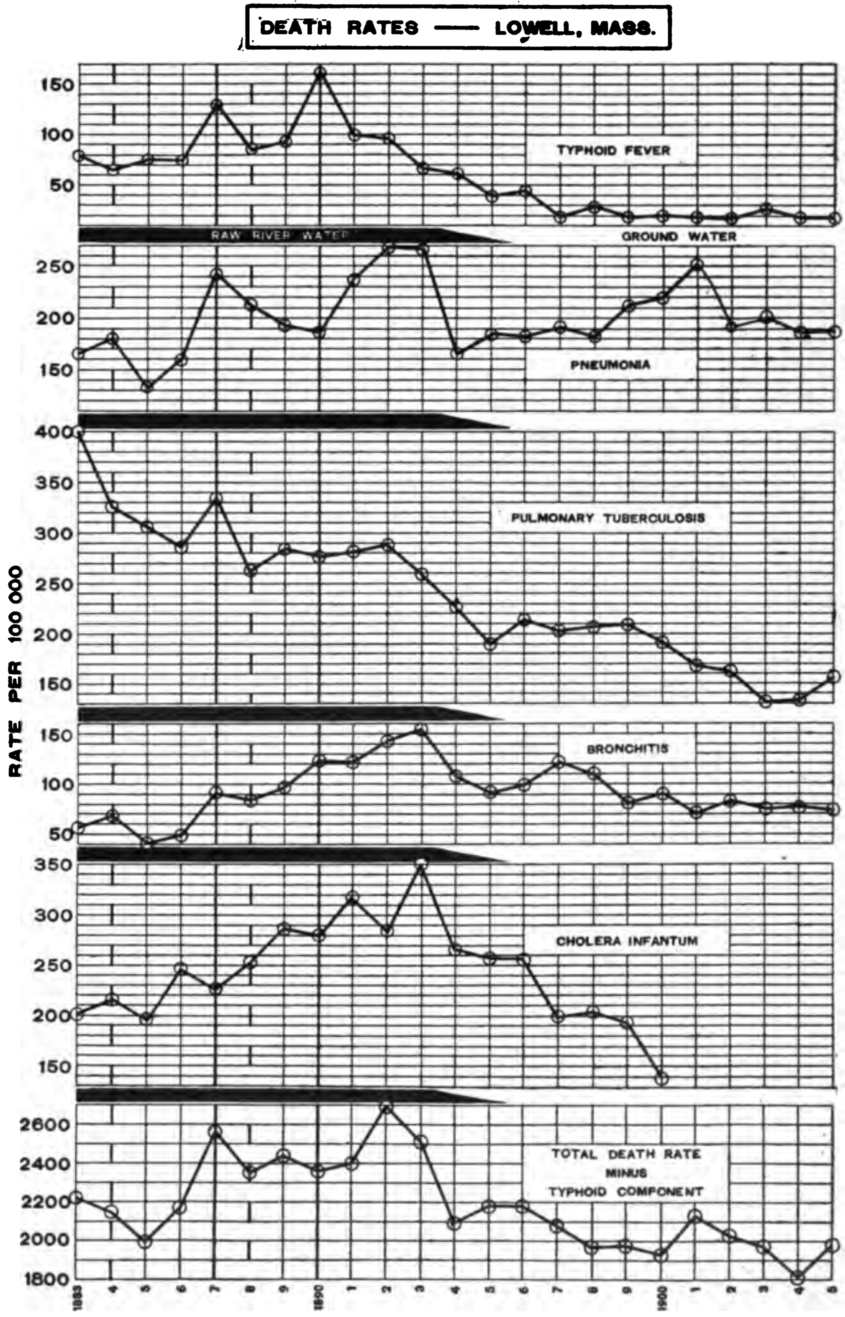
DEATH RATES —— LOWELL, MASS.
RATE PER 100 000
TYPHOID FEVER
150
100
50
RAW RIVER WATER
GROUND WATER
PNEUMONIA
250
200
150
PULMONARY TUBERCULOSIS
400
350
300
250
200
150
BRONCHITIS
150
100
50
CHOLERA INFANTUM
350
300
250
200
150
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
2600
2400
2200
2000
1800
1883
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5

CHART 5.

in general maintained, tho with certain fluctuations, up through the last year shown.

Pulmonary tuberculosis had been declining steadily prior to 1894, and from the curve no influence of purification of water-supply can be demonstrated, but that in this disease also the benefits of the better water were felt is clearly indicated by the analytical study in our contribution to the volume "Tuberculosis in Massachusetts" (referred to, p. 491 above) and by later study in sec. xvi of the present paper.

Bronchitis had been rising rapidly, up to the critical years 1894 and 1895, but at this time the whole trend of the curve was reversed, a distinct fall setting in—more rapid at first, and later settling gradually to the comparatively low level maintained for the last seven years of the period.

One of the most striking effects is seen in cholera infantum, which had been on the increase for some years before introduction of ground-water, but immediately afterward showed a rapid descent. Unfortunately reliable data for 1901 ff. were not available, but these years are less important than the years immediately following purification.

Finally, we discover, as at Lawrence, in the last curve of the chart an extraordinary demonstration of the Mills-Reincke phenomenon. The total death-rate minus typhoid component, which had risen as high as 27 and had scarcely gone below the excessive rate of 24 in the seven years prior to the critical years 1894–95, now shows in 1894 the surprising drop to a level of 21, sinking in subsequent years even lower.

XV. A GRAPHICAL DEMONSTRATION OF THE PHENOMENA AT MANCHESTER, NEW HAMPSHIRE, A CITY HAVING A WATER-SUPPLY OF GOOD QUALITY.

As a control or norm with which the phenomena at Lawrence and Lowell may be compared we have taken Manchester, N.H., a city which, as we have already stated, is in all important respects closely similar to Lawrence and Lowell. This similarity may be demonstrated statistically by reference to the U.S. Census for 1890 and 1900 and the Massachusetts State Census for 1895. We have taken from those sources figures relating to age, sex, and nativity distribution, and occupations of the population, which not only demonstrate the similarity of the three cities in the respects stated but also the fact that the three censuses show no significant differences in the percentages. It is a well-known fact that the mortality rates of communities may be considerably affected by the age distribution of the population, since death-rates are much higher for the very young and the very old. The death-rates of the age-groups under five years and over forty-five years are usually higher than that of the whole population, whereas the death-rates of other ages are lower, tho the limits may vary somewhat for different cities. By reference, for instance, to the Massachusetts State Registration Report for 1895, we ascertain the death-rate for that year for the whole population to be 19.01 per 1,000; the rate for the age-group under five years, 64; for the group five–ten, 6; for succeeding age-groups up to fifty, rates less than 19; but for all groups above fifty, rates higher again than that for the whole population. Again, as is well known, general death-rates are affected to greater or less extents by distribution according to sex, place of birth, and occupations of the population. We therefore present without further comment the following table:

TABLE 11.*

RATIOS OF:	PERCENTAGES							
	LAWRENCE			LOWELL			MANCHESTER	
	1890	1895	1900	1890	1895	1900	1890	1900
Age-groups under five and over forty-five to total population	28.0	28.2	28.6	27.4	27.9	28.4	27.2	29.1
Male population to total population	46.6	48.2	48.3	45.6	46.1	47.3	45.0	46.7
Persons born in Canada (English) to total population	10.0†	2.0	2.7	20.3†	1.9	4.7	28.1†	3.0
Persons born in Canada (French) to total population		8.9	11.2		15.2	15.4		23.6
Persons born in Great Britain‡ to total population	13.7	12.9	10.2	6.6	6.7	5.9	3.5	3.1
Persons born in Germany to total population	4.1	4.6	3.9	0.2	0.2	0.2	2.0	2.0
Persons born in Ireland to total population	17.2	14.4	11.3	16.3	14.9	12.8	9.8	7.4
Persons born in other countries to total population	0.9	3.8	6.4	1.1	5.3	4.1	2.1	3.5
Total foreign-born	45.9	46.6	45.7	44.5	44.2	43.1	45.5	42.6
Wage-earners to total population	34.9	....	35.7	35.7	....	33.0	34.8	33.4
Textile operatives¶ to total wage-earners	68.9	....	76.1	63.7	....	65.0	62.2	58.7

* Computed from U.S. Censuses, 1890 and 1900, and Massachusetts Census, 1895.

† Canada and Newfoundland.

‡ England, Scotland, and Wales.

¶ Workers in manufacture of cotton, woolen, knit, and worsted goods, and hosiery.

Thus the above statistics confirm and supplement the knowledge gained by the personal familiarity of the authors with these three cities that they are in all important respects closely similar.

The statistics upon which we have based our studies of Manchester are presented in Tables 12 and 13.

TABLE 12.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
Same water-supply, of good quality, throughout:													
1880	‡32,630												
1883¶	35,220	760	20	54	7	116	131						
1884	37,230	764	17	46	18	117	112						
1885	38,380	783	22	55	20	107	88						
1886	39,530	748	15	33	9	118	122						
1887	40,680	814	18	51	31	90	148						
1888	41,830	869	14	55	37	115	117	55	11	31	46	24	5
1889	42,980	778	18	53	35	78	86	49	18	22	47	18	12
1890	‡44,126	973	15	83	40	106	146	28	18	36	43	27	22
1891	45,410	895	19	85	38	98	122	9	15	24	42	18	17
1892	46,700	980	5	50	38	91	102	11	21	20	56	20	24
1893	47,980	1,013	14	66	43	91	86	7	23	21	44	28	13
1894	49,270	1,001	23	86	59	92	138	37	15	38	55	13	13
1895	50,560	1,036	21	107	55	83	144	26	19	47	80	22	16
1896	51,840	1,064	19	90	54	126	115	45	17	29	77	21	21
1897	53,130	1,140	12	119	88	111	123	38	29	39	70	18	22
1898	54,410	1,003	14	89	47	88	136	26	26	33	53	15	31
1899	55,700	1,061	11	134	65	101	92	13	31	61	69	21	31
1900	‡56,987	1,153	9	120	39	117	148	13	34	56	84	21	30
1901	58,270	1,143	9	115	37	104	132	8	27	35	88	13	36
1902	59,560	1,088	8	121	55	78	§	30	38	§	72	20	28
1903	60,850	1,112	9	112	41	79	§						
1904	62,130	1,015	12	101	31	87	§						
1905	63,420	1,339	11	129	22	108	§						

---

* From N.H. State Registration Reports, except last four columns, which were kindly furnished by Dr. Irving A. Watson, State Registrar of Vital Statistics, N.H. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank. Stillbirths are excluded.

† Including angina pectoris, embolism, and phlebitis.

‡ U.S. Census years. Intermediate populations interpolated by the "arithmetical" method.

¶ Year ending March 31, 1883.

§ Change of classification.

From these death-rates we have constructed the diagrams in Chart 6, using the same method of plotting as for Hamburg, Lawrence, and Lowell. As Manchester had a water-supply of good quality throughout, there are no black bars.

Typhoid fever remained at a fairly low level throughout the period, and this was to be expected from the character of the water-supply. This curve therefore affords a valuable background for viewing the typhoid fever death-rates of the other two cities.

TABLE 13.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
1883	‡2,158	57	153	20	329	372						
1884	2,052	46	124	48	314	301						
1885	2,040	57	143	52	279	229						
1886	1,892	38	84	23	299	309						
1887	2,001	44	125	76	221	364						
1888	2,077	33	132	88	275	280	132	26	74	110	57	12
1889	1,810	42	123	81	181	200	114	42	51	109	42	28
1890	2,205	34	188	91	240	331	63	41	82	97	61	50
1891	1,971	42	187	84	216	269	20	33	53	93	40	37
1892	2,099	11	107	81	195	219	24	45	43	120	43	51
1893	2,111	29	138	90	190	179	15	48	44	92	58	27
1894	2,032	47	175	120	187	280	75	30	77	112	26	26
1895	2,049	42	212	109	164	285	51	38	93	158	44	32
1896	2,052	37	174	104	243	222	87	33	56	149	41	41
1897	2,146	23	224	166	209	232	72	55	73	132	34	41
1898	1,842	26	164	86	162	250	48	48	61	97	28	57
1899	1,905	20	240	117	181	165	23	56	109	124	38	56
1900	2,023	16	210	68	205	260	23	60	98	147	37	53
1901	1,962	15	197	64	179	227	14	46	60	151	22	62
1902	1,827	13	203	92	131	...	50	64	...	121	34	47
1903	1,827	15	184	67	130	...						
1904	1,634	19	163	50	140	...						
1905	2,111	17	204	35	170	...						

* Computed from preceding table.

† Including angina pectoris, embolism, and phlebitis.

‡ Year ending March 31, 1883.

Same surface water-supply, of good quality, throughout.

Pneumonia was rising steadily tho irregularly until 1899, and at the very time (1894) when Lawrence experienced an extraordinary drop in pneumonia and Lowell one nearly as great, the rate for Manchester had risen higher than it had ever been before in the period considered; and then while the rates at Lawrence and Lowell remained at the level to which they had fallen, that at Manchester, on the whole, rose.

For pulmonary tuberculosis the Manchester curve, like those for the other two cities, was throughout the period falling gradually, but its rate of fall was in comparison not so rapid, the years 1896 and 1897 even showing a marked rise.

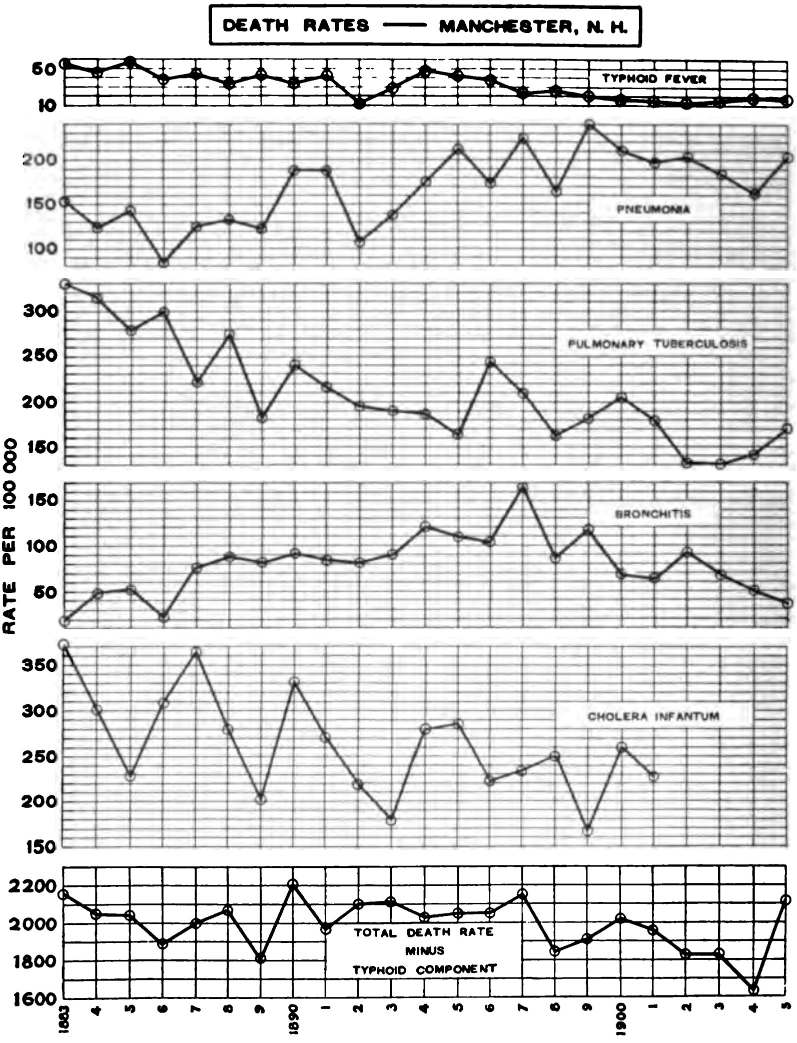

CHART 6.

Bronchitis, like pneumonia, was rising at Manchester until 1897, while at Lowell there was a decline in this disease following the introduction of ground-water. At Lawrence the decrease in bronchitis had already set in before filtration, hence without the further detailed studies which we present in sec. xvi, the fact that Lawrence experienced a greater decline than the norm cannot be readily seen.

In cholera infantum the curve for Manchester is highly irregular, but in the years 1894 and 1895, when that disease had dropped markedly in the other two cities, the rate for Manchester had risen to a maximum.

In the curve for total death-rate minus typhoid component Manchester shows a close adherence to a level of about 2,000 from 1892 to 1897, thus covering the period when Lawrence and Lowell changed their water-supplies and experienced remarkable drops in that death-rate, which had in these two cities been at a much higher level.

We shall not pause here any longer to discuss Lawrence and Lowell as compared with Manchester, reserving for sec. xvi the detailed study of the comparative relations among these three cities.

XVI. A COMPARATIVE STUDY OF THE DATA DERIVED FROM LAWRENCE, LOWELL, AND MANCHESTER.

We have seen in secs. xiii, xiv, and xv that both at Lawrence and at Lowell there followed immediately upon purification of the water-supply a lasting drop in the total death-rate—a drop much greater than could be accounted for by the decrease in typhoid fever alone; while the total death-rate at Manchester showed no such change, but kept steadily on the same comparatively low level.

The drops at Lawrence and Lowell we shall examine somewhat more closely in order to determine: (1) the extent of the reductions in their total death-rates in comparison with the norm, Manchester; and (2) what causes of death played the principal parts in these reductions. Throughout we shall compare Lawrence and Lowell with each other and with the norm, Manchester.

In the analysis of the declines we have first taken seven chief causes of death, omitting "accident," as given in the tables of the Massachusetts State Registration Report for 1890. These are: phthisis, causing in that year 5,791 deaths; pneumonia, 4,038; cholera infantum, 2,491; diphtheria and croup, 1,626; bronchitis, 1,533; apoplexy, 1,301; and typhoid fever, 835; making a total of 17,615 deaths. The total number of deaths in Massachusetts for the year was 43,528. In addition to this list we have taken several important general headings given in most nosological arrangements, in order to include diseases of all the general classes, viz.: inanition, marasmus, and infantile debility; heart disease; old age; and diseases of the kidneys. The sum of all titles above mentioned formed 50 to 60 per cent of the total deaths in Manchester, Lowell, and Lawrence, and if causes of death other than disease be omitted, the percentage is somewhat higher.

It may be objected that a few of these titles, e.g., old age, are too vague to serve in an accurate analysis, and the objection is valid so far as exact and absolute determinations of mortality are concerned. For purposes of comparison of the rates in the same city at periods not much separated, however, the indefiniteness of any given title does not greatly affect its value in the analysis. The limits covered by any title depend upon the local usage of the medical profession in the community in question; and as such usage commonly changes only gradually, year to year comparisons are not seriously interfered with. The important phenomena considered in this paper are *sudden* decreases in death-rates taking place within a short space of time.

Mortality statistics for the various causes of death, illustrating the phenomena at Lawrence and Lowell, as compared with the norm, Manchester, before and after water-supply purification, are given in Tables 14 and 15. By the use of averages for periods of five years before and after, a safer if less striking view of the facts is obtained.

From the first of these tables have been plotted Charts 7 and 8, which largely explain themselves. It must be observed that the periods of five years each, before and after water-supply purification, do not quite correspond for Lawrence and Lowell, so that the corresponding Manchester blocks in the upper and lower halves of the chart do not represent exactly the same periods for that city.

These diagrams demonstrate certain points which do not clearly appear in the curves in Charts 4 and 5, one of the chief advantages being that the movements of the rates in Manchester, the norm, are readily seen in direct comparison with those in the other two cities. Thus, for example, the stationary bronchitis rate at Lawrence is seen to be actually a gain because that at Manchester increased; a point which does not appear in the Lawrence curve alone.

In order that the actual extent of the decreases in death-rates may be determined, reckoned against the corresponding changes at Manchester, as well as independently, we have also made the computations presented in Table 16.

TABLE 14.

MORTALITY RATES FROM CERTAIN DISEASES IN LAWRENCE, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of filtration at Lawrence.

	LAWRENCE		MANCHESTER	
	1888–1892 (Before)	1894–1898 (After)	1888–1892 (Same Periods as for Lawrence)	1894–1898
Typhoid fever	119	32	32	35
Pneumonia	255	202	148	190
Bronchitis	49	47	85	117
Pulmonary tuberculosis	244	185	222	192
Cholera infantum	222	201	260	254
Diphtheria and croup	152*	59	71	67
Apoplexy	55	62	37	41
Inanition, marasmus, and infantile debility	146	100	61	72
Heart disease	126	119	106	130
Old age	42	37	49	35
Diseases of the kidneys	36	36	36	39
Total death-rate	2,494	1,998	2,032	2,024

* Epidemic in 1889, when the rate rose to 391.

TABLE 15.

MORTALITY RATES FROM CERTAIN DISEASES IN LOWELL, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of ground-water at Lowell.

	LOWELL		MANCHESTER	
	1889–1893 (Before)	1896–1900 (After)	1889–1893 (Same Periods as for Lowell)	1896–1900
Typhoid fever	103	26	32	24
Pneumonia	230	197	149	202
Bronchitis	127	100	85	108
Pulmonary tuberculosis	278	205	205	200
Cholera infantum	304	198	240	226
Diphtheria and croup	57	42	47	51
Apoplexy	58	70	42	50
Inanition, marasmus, and infantile debility	234	143	55	79
Heart disease	181	181	102	130
Old age	78	50	49	36
Diseases of the kidneys	73	72	39	50
Total death-rate	2,581	2,051	2,039	1,994

From these figures it is seen that when the decreases in Manchester are taken into account, and subtracted algebraically with the proper signs, as normal, from those in the other two cities, the declines in certain diseases in the latter cities stand out from the obscurity

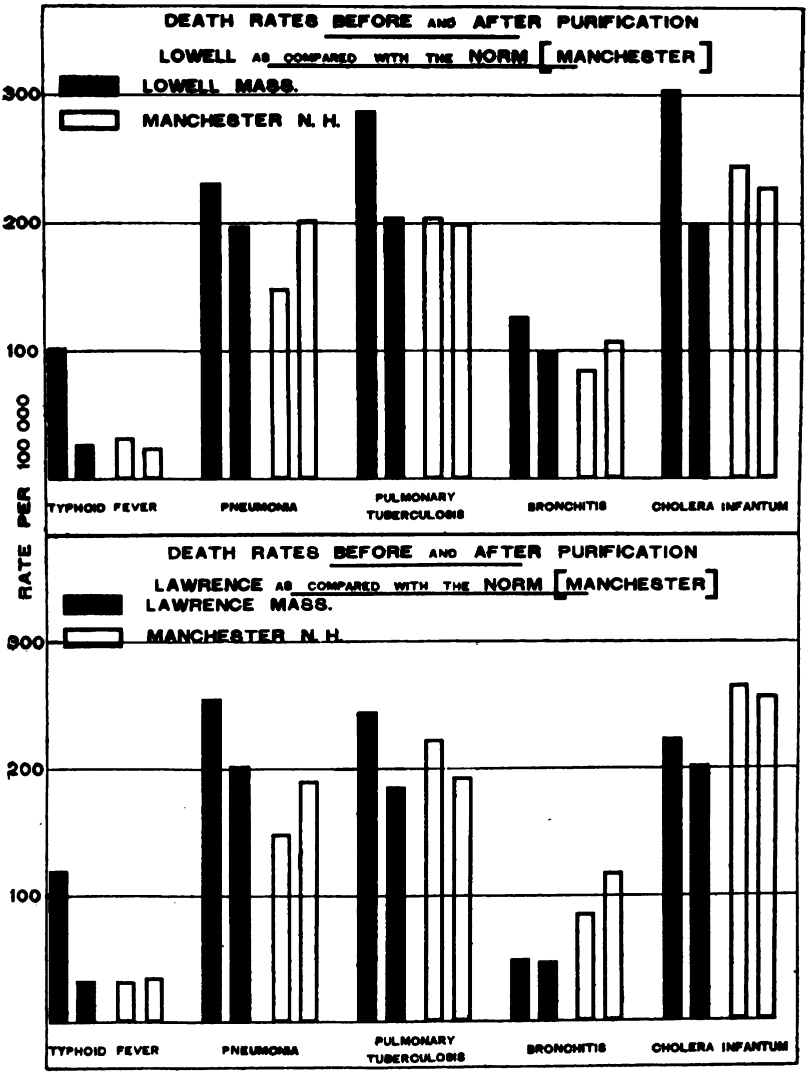

CHART 7.

in which they are masked when only the actual decreases are considered. Chief among these diseases are pneumonia and bronchitis.

Taking up first typhoid fever, and referring to Chart 7 as well as to the tables just given, we find that the rates at Manchester from that disease show the good and unvarying quality of the water-supply there, thus demonstrating the city's normality in that respect. The great drops at the other two cities following water-supply purification stand out clearly.

TABLE 16.

DECREASES IN DEATH-RATES FROM CERTAIN CAUSES IN LAWRENCE AND LOWELL FOLLOWING WATER-SUPPLY PURIFICATION.

Rates are per 100,000 population.

CAUSES OF DEATH	DECREASES IN DEATH-RATES							
	APPARENT (COMPUTED DIRECTLY)				TRUE (SUBTRACTING ALGEBRAIC DECREASE AT MANCHESTER AS NORMAL)			
	LAWRENCE		LOWELL		LAWRENCE		LOWELL	
	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease
Typhoid fever	87	18	77	15	90	18.5	69	14
Pneumonia	53	11	33	6	95	19.5	86	18
Bronchitis	2	0	27	5	34	7	50	10
Pulmonary tuberculosis	59	12	73	14	30	6	68	14
Cholera infantum	21	4	106	20	15	3	92	19
Diphtheria and croup	93	19	15	3	89	18	19	4
Inanition, marasmus, and infantile debility	46	9	91	17	57	12	115	24
Old age	5	1	28	5	−9	−2	15	3
Other causes	130	26	80	15	87	18	−29	−6
All causes	496	100	530	100	488	100	485	100

In respect to pneumonia, while Manchester rose markedly from 148 to 190, Lawrence dropped from the high rate of 255 to the normal of 202. Lowell shows a similar decrease. In both cases the closeness of the rates, after improvement, to those of Manchester is additional evidence for the conclusion that the polluted water had caused an abnormally high rate, which declined at once, on the removal of the pollution, to the normal level.

Pulmonary tuberculosis was decreasing in Massachusetts and New Hampshire during the period 1890–1900. The diminution for the state of Massachusetts—shared fully, as detailed study shows, by cities of the same class as Lawrence and Lowell—is indicated by the following rates per 100,000 from the state registration: for 1890, 259; for 1895, 219; and for 1900, 185. Similarly in New Hampshire the rates were: for 1890, 219; for 1895, 177; and for 1900, 158. In a comparison of Manchester and Lawrence, both cities show a decrease, but that in Manchester is comparatively small. The decrease in the latter is what might be expected from general improvement in sanitary conditions. Lawrence starting higher came down to about the level of the norm. Lowell shows the same phenomenon as compared with Manchester, but in much more marked degree. In actual figures Lawrence shows a decrease 30 greater than the normal, and Lowell, 68 greater. These facts, in spite of many complicating factors, indicate a certain amount of decrease due to the change in water-supply. Phthisis being a disease of slow development and often long-postponed fatality, an effect on the mortality could hardly be expected to appear immediately after an improvement in one condition favoring its spread or fatality; and where many such conditions are involved the effect might well be somewhat obscured. We wish therefore to emphasize particularly the evidence here given that both at Lawrence and at Lowell there were decreases in pulmonary tuberculosis following water-supply purification considerably greater than the corresponding normal decreases at Manchester, as this point is not distinctly demonstrable by the curves for the former cities alone.

Bronchitis, which includes both chronic and acute disease, shows much the same phenomena as does pneumonia. At Manchester the rate rose distinctly; at Lawrence, however, it did not rise, but remained stationary; while at Lowell there was actually a decrease amounting to 50 more than the normal decrease. This also is a case of improvement which is much better demonstrated by the blocks of Chart 7 than by the curves.

Cholera infantum, a general title indicative of intestinal diseases of infants, shows a decrease in all three cities. In Lawrence, however, there was a decrease of 15 more than the normal, while Lowell shows a remarkable corresponding surplus decrease of 92. The latter stands out as one of the most striking phenomena observed, and recalls with emphasis Dr. Reincke's statement that the mixing of raw river water with milk caused much of the infant mortality at Hamburg (pp. 497, 500, 502, above). The same explanation probably also holds good to a very great extent for Lawrence and Lowell.

Among the minor causes of death not plotted in the charts, tho included in the tables, we consider first inanition, marasmus, and infantile debility, a heterogeneous and indefinite title, but one fairly indicative of the mortality of the feeble. Infantile debility makes up a large part of it, and probably a considerable number of deaths from diarrhea and the gastro-intestinal diseases of infants are here included through false diagnosis. As seen from the tables, both at Lawrence and at Lowell the mortality shows a great decrease, while at Manchester a considerable rise took place. On account of the tendency in diagnosis just mentioned it well may be that much of the effect of water-supply purification at Lawrence upon infant mortality is indicated by this title, the cholera infantum rate not having been much lowered.

For old age the figures indicate a slight rise at Lawrence, but at Lowell a decrease distinctly greater than the normal.

Heart disease (uncertain in diagnosis) shows improvements greater than the normal by about 30.

In diseases of the kidneys and apoplexy there are no phenomena worthy of mention.

With reference to diphtheria and croup the mixt character of the title, the highly epidemic character of diphtheria, and the use of antitoxin complicate matters so much that we can draw no conclusions from the figures.

The Mills-Reincke phenomenon at both Lawrence and Lowell is shown very strikingly by Chart 8. (We must caution the reader, that in order to save space the blocks in this chart have been cut off so that their true bases do not appear.) Here the drops seen in the curves in Charts 4 and 5 are reduced to actual quantitative statement for five-year periods just before and after water-supply purification. At Lawrence the total death-rate minus typhoid component dropped from 23.7 to 19.7 per 1,000 with an annual saving of about 200 lives from causes other than typhoid fever. At Lowell it dropped from 24.8 to 20.3, with a saving of 365 lives from such causes. Manchester, on the other hand, shows decreases for the corresponding periods of only 0.1 and 0.4 respectively. In other words, the

REDUCTION IN DEATH RATE
FROM
DISEASES OTHER THAN TYPHOID FEVER
FOLLOWING
WATER SUPPLY PURIFICATION

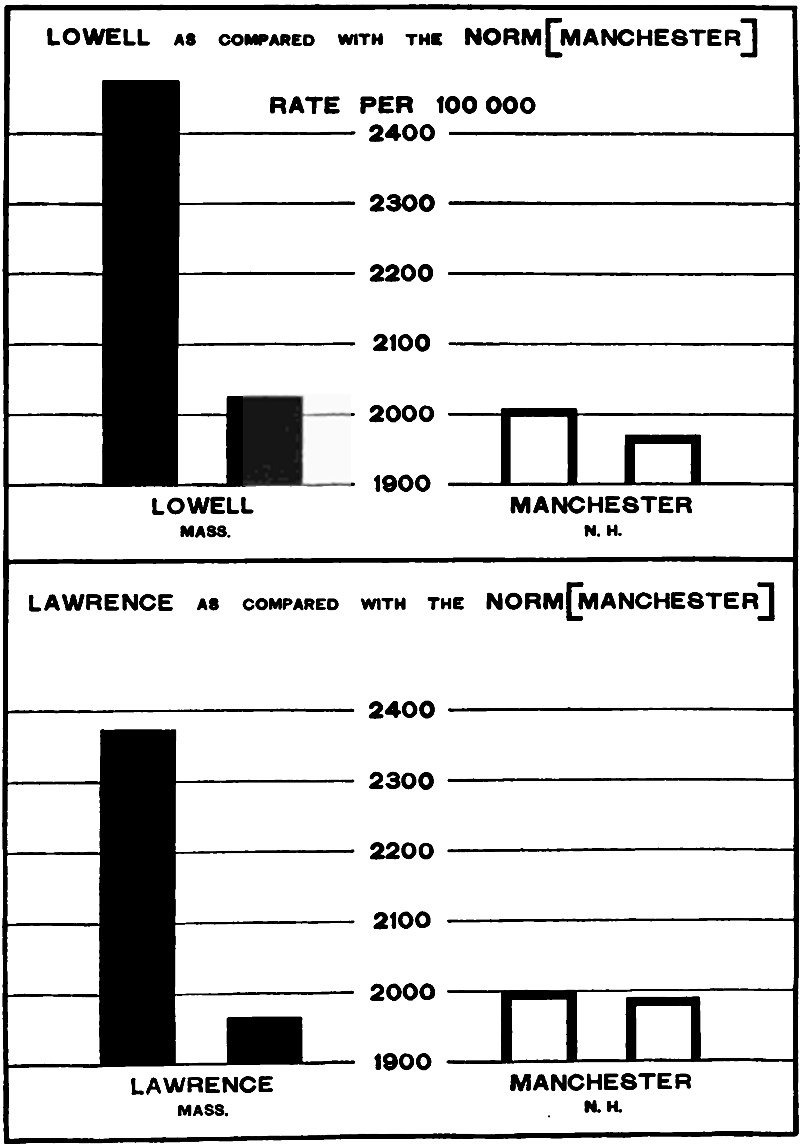

CHART 8.

first two cities, which had used polluted and unpurified water-supplies and had had very excessive "total minus typhoid" death-rates, dropped after purification to the normal and comparatively low rate level (*ca.* 20.0) which Manchester had maintained throughout.

The second of the two questions proposed at the outset of this section, i.e., what causes of death played the principal parts in the reductions in the total death-rates, is also answered in Table 16 above, by the percentage columns. If the rates for Lawrence and Lowell be averaged, over 80 per cent of the decreases in total death-rates—whether actual or comparative (against Manchester) rates be considered—are accounted for. In this decrease, the chief parts were played (besides typhoid fever) by pneumonia, pulmonary tuberculosis, cholera infantum, and inanition, marasmus, and infantile debility. Cholera infantum and the last three causes of death are, as we have already stated, somewhat related by diagnosis. And these results agree with those already obtained for Hamburg (secs. iv and v).

The foregoing analysis affords a basis for a testing of Hazen's theorem. As a preliminary computation we find that at Lawrence, for every death less from typhoid fever there were 4.7 deaths fewer from other causes, and at Lowell 5.9 fewer. These, however, are only crude ratios which include any rises or falls of the rates which would have taken place in any event independent of water-supply purification. It is therefore necessary, in order to obtain ratios comparable with that suggested by Mr. Hazen (which was based upon computations from which decreases due to causes other than water-supply purification had been approximately eliminated), to consider the decreases *minus* those at Manchester as normal. We compute, therefore, from Table 16, that—

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths [*4.4 at Lawrence and 6.0 at Lowell*] from other causes have been avoided.

Thus Mr. Hazen's estimate of two or three is seen to have been for these cities very conservative.

At this point we may briefly consider certain objections which may perhaps be raised against the accuracy of the foregoing statistical studies or our interpretation of them. We have already shown (sec.

iv) that for three census years (1890, 1895, and 1900) the age and sex distributions, the proportions of foreign-born of various nationalities, and the occupations of the population at Lawrence and Lowell were practically the same. Between census years there were undoubtedly fluctuations in these conditions, but any such could have been only temporary, as otherwise they would be indicated by the census figures. Of fluctuations in the actual number of the total population as related to population estimates we have made a special study, the results of which are submitted in sec. xviii. Anticipating, we may state here our conclusion that no error seriously affecting our results has been introduced from that direction. Moreover, important fluctuations in quality or quantity of population at Lawrence and Lowell should have had a counterpart at Manchester, a city in all essential respects similar, with which comparisons have throughout been made. The same remark applies also to mortality decreases due to general sanitary and medical improvement (upon which, it will be remembered, Dr. Reincke laid considerable stress in the case of Hamburg).

Such *sudden* and *lasting* decreases in death-rates as took place in each of these cities can be explained only by sudden and permanent measures of sanitation, and it is impossible to escape the conclusion that the principal part in the drop in total death-rate—the Mills-Reincke phenomenon—both at Lawrence and at Lowell, was played by the purification of the public water-supply.

XVII. STUDIES OF SIMILAR PHENOMENA IN SOME OTHER AMERICAN CITIES

1. *Albany, N.Y.* — As another example of the Mills-Reincke phenomenon occurring in a prominent city which has purified its public water-supply and for which reliable vital statistics are obtainable, we present Albany, N.Y.

Previous to 1899 two-thirds of the total water-supply of this city was taken from the Hudson River without purification, while the remaining third came by gravity from watersheds just west of the city. In September, 1899, slow sand filtration of the Hudson River supply was introduced, while the surface water-supply remained unchanged. The statistics upon which we have based our demonstration of the Albany phenomena are given in the following Tables 17 and 18.

The death-rates for Albany are plotted on Chart 9, in which the same methods of presentation are employed as for Hamburg, Lawrence, and Lowell.

TABLE 17.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, ALBANY, N.Y., 1885–1907 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:							
1880	†90,758						
1885	92.841	1,993	49	182	299	101	685
1886	93,257	‡2,005	‡79	‡255	‡302	‡117	‡667
1887	93,674	2,020	71	203	337	121	561
1888	94,090	2,332	74	283	312	137	773
1889	94,507	2,262	77	297	294	81	741
1890	†94,923	2,265	62	386	327	124	641
1891	94,846	2,383	108	421	310	150	632
1892	94,769	2,558	50	448	298	165	863
1893	94,692	2,140	58	381	257	103	578
1894	94,615	2,162	52	326	301	118	656
1895	94,538	2,345	162	311	287	147	697
1896	94,461	2,099	97	244	298	126	556
1897	94,384	2,013	84	312	259	107	490
1808	94,307	1,904	94	225	238	88	464
1899	94,230	1,991	82	263	248	72	510
After filtration:							
1900	†94,151	1,742	38	256	231	70	382
1901	94,996	1,751	20	220	239	42	298
1902	95,841	1,623	29	227	215	37	251
1903	96,686	1,808	19	242	228	39	321
1904	97,531	1,848	18	258	216	§	281
1905	¶98,374	1,813	19	227	212	§	329
1906	99,219	1,770	20	§	193	§	322
1907	100,064	1,900	20	§	177	§	313

* From Reports of the N.Y. State Dept. of Health.

† U.S. Census. ¶ State Census. Other populations interpolated by the "arithmetical" method.

‡ Eleven months only, December not being given.

§ Title discontinued in reports.

Typhoid fever, which had been excessively prevalent, dropped immediately after the introduction of filtration to a much lower level. In addition to this there took place a decrease in the total death-rate minus the typhoid component, Albany thus furnishing another illustration of the Mills-Reincke phenomenon. This fact was noticed and reported by Mr. Mills and others, before our work began.

The decreases in the mortality from certain diseases at Albany are somewhat different in degree from those observed at Lawrence, Lowell, and Hamburg. Altho the death-rates at Albany from acute respiratory diseases, pulmonary tuberculosis, and "diarrheal diseases" (not including typhoid fever) were lower after the introduction of filtration than before, it must be noted that all three rates had been declining before that time, and that in none of them does there appear any greater rapidity of decline setting in at this time. The most noticeable result shown by any curve of chart (except that for typhoid fever) appears in the death-rate under five years of age, for which the rate of decline just subsequent to 1899 was somewhat greater than it had been before. Falling to about 300, it continued at that level up through the last year we have taken, 1907. This phenomenon is not, however, clearly reflected in the curve for total death-rate minus typhoid component, which shows no greater rapidity of decline after introduction of filtration. But even the fact that the decline in total death-rate continued as rapid as before may be in part due to the improvement of the water-supply, for it might perhaps otherwise have risen. The effect, nevertheless, is not nearly so clear-cut as in the cases of Hamburg, Lawrence, and Lowell, and requires explanation. Such explanation we believe

TABLE 18.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, ALBANY, N.Y., 1885 TO 1907 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:						
1885	2,147	53	196	322	109	738
1886	†2,150	†85	†274	†324	†126	†716
1887	2,157	76	217	360	129	599
1888	2,478	79	301	332	146	821
1889	2,393	81	314	312	86	784
1890	2,386	65	407	345	131	675
1891	2,512	114	444	327	158	667
1892	2,699	53	472	315	174	911
1893	2,260	61	402	271	109	610
1894	2,285	55	345	318	125	694
1895	2,480	171	329	304	156	738
1896	2,222	103	259	316	134	589
1897	2,133	89	331	274	114	519
1898	2,019	100	239	252	93	492
1899	2,113	87	279	263	76	542
After filtration:						
1900	1,850	40	272	246	74	406
1901	1,843	21	232	252	44	314
1902	1,693	30	237	224	39	262
1903	1,870	20	250	236	40	332
1904	1,895	18	265	222	‡	288
1905	1,843	19	231	216	‡	334
1906	1,783	20	‡	194	‡	325
1907	1,899	20	‡	177	‡	313

* Computed from preceding table. Slow sand filter since September, 1899, for Hudson River water, which furnishes about two-thirds of total supply. One-third of supply, both previous and subsequent to introduction of filtration, has been composed of impounded surface water.

† Eleven months only.

‡ Title discontinued in reports.

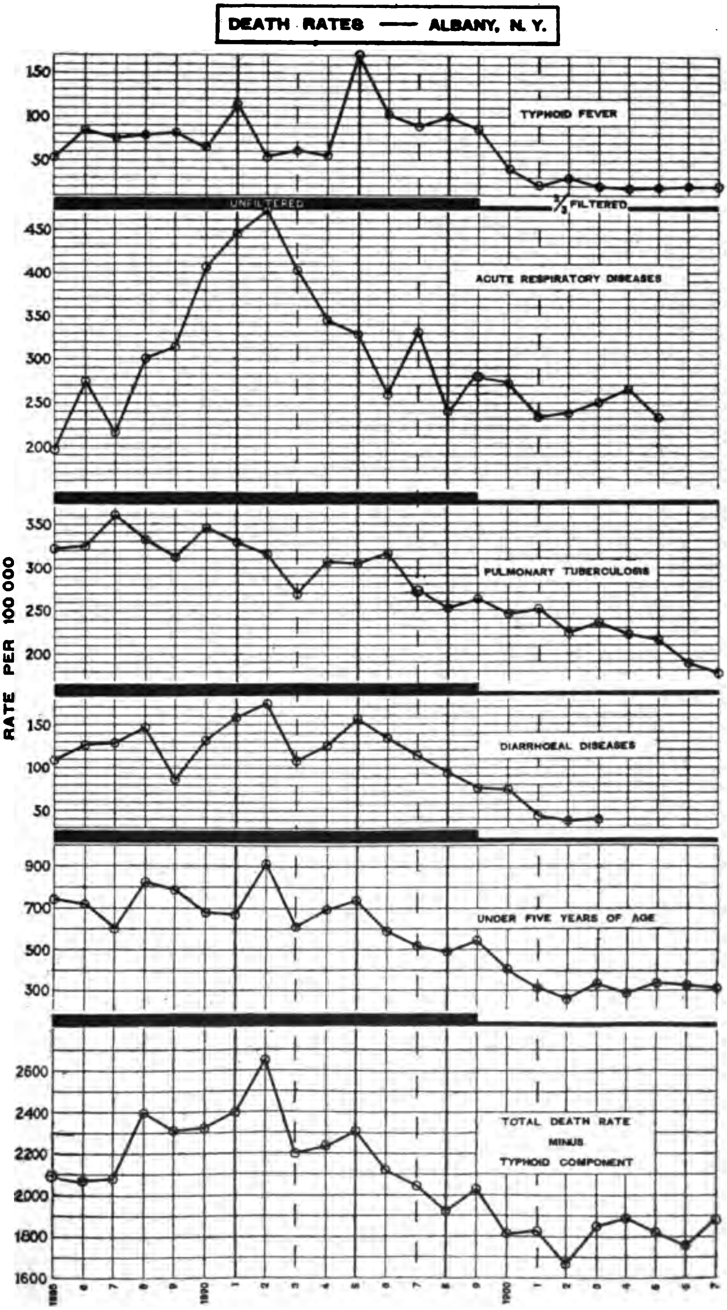
DEATH RATES —— ALBANY, N. Y.
TYPHOID FEVER
150
100
50
UNFILTERED
2/3 FILTERED
ACUTE RESPIRATORY DISEASES
450
400
350
300
250
200
PULMONARY TUBERCULOSIS
350
300
250
200
RATE PER 100 000
DIARRHOEAL DISEASES
150
100
50
UNDER FIVE YEARS OF AGE
900
700
500
300
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
2600
2400
2200
2000
1800
1600
1885
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5
6
7

CHART 9.

may possibly be found in the fact that one-third of the water-supply has come, and still comes, without purification, from the surface sources mentioned, the quality of which is said to be somewhat uncertain. It is possible at any rate that if the whole of a supply be not purified, the resultant drop in total death-rate minus typhoid component may be much less, even tho there be, as in this case, a decided diminution in typhoid fever. We greatly regret that we have had no such personal familiarity with conditions at Albany as we have enjoyed with the various cities on the Merrimac River, and that we must leave to others possessing fuller acquaintance with local conditions the task of clearing up local difficulties.

From average death-rates for periods of five years before and after the introduction of filtration (omitting the year 1899 itself), we compute that for every death less from typhoid fever after that date, there were still, even here, 4.1 fewer from other causes. This ratio is of course uncorrected for diminutions in mortality due to other factors than filtration, so that, tho affording an approximate indication, it cannot strictly be substituted in Hazen's theorem.

2. *Binghamton, N.Y.* — Among other examples of the Mills-Reincke phenomenon which have come to our attention, we may include Binghamton, N.Y., altho this city exhibits great irregularities which distinguish it from the examples we have already discussed. Binghamton took its water-supply without purification from the Susquehanna River until June, 1902, when mechanical filtration was introduced. Certain vital statistics for this city are given in Table 19.

From these figures our Chart 10 has been constructed. It will be observed that, following the introduction of filtration, the typhoid fever death-rate, which had been excessive, tho irregular, fell to a low level and remained there. The total death-rate minus typhoid component reflected this fall, altho one year, 1904, shows a rate higher, with the exception of only two previous years, than any rate since at least 1885. This irregularity shows that this is not altogether a clear case of the Mills-Reincke phenomenon, and therefore requires for a complete solution further elucidation.

Altho the authors have been unable to give to the case any local study such as it imperatively demands, certain facts deserve mention. In the first place, both curves had before filtration shown very great irregularities, that for total death-rates minus typhoid component in particular having at one time fluctuated from 13 to 20 inside of four years. Typhoid fever had in certain years receded to a comparatively low rate, and the same is true of the total death-rate. When we consider, also, the small numbers with which we have to deal and the consequent unsteadiness of the statistics, it becomes evident that, in the absence of more detailed and thorough local studies, too much reliance should not be placed upon them.

TABLE 19.

VITAL STATISTICS OF BINGHAMTON, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:	†17,317				
1880					
1886	27,929	3	11	333	11.9
1887	29,698	14	47	433	14.6
1888	31,467	32	102	493	15.7
1889	33,236	34	102	465	14.0
1890	†35,005	21	60	545	15.6
1891	35,469	32	90	668	18.8
1892	35,933	18	50	667	18.6
1893	36,397	16	44	622	17.1
1894	36,861	18	49	584	15.8
1895	37,325	13	35	540	14.5
1896	37,789	9	24	494	13.1
1897	38,253	13	34	498	13.0
1898	38,717	28	72	584	15.1
1899	39,181	10	26	681	17.4
1900	†39,647	17	43	822	20.7
1901	40,125	21	52	755	18.8
1902	40,603	11	27	725	17.9
After:					
1903	41,081	4	10	619	15.1
1904	41,559	4	10	762	18.3
1905	‡42,036	5	12	678	16.1
1906	42,514	5	12	678	15.9
1907	42,992	8	19	673	15.6

* Compiled and computed from Reports of N.Y. State Dept. of Health.

† U.S. Census ‡ State Census. Other population figures interpolated by the "arithmetical" method. Mechanical filter since June, 1902.

On going through the Annual Reports of the New York State Board of Health in an endeavor to discover, if possible, the specific reason or reasons for the peak in total death-rate minus typhoid component in 1904, we have found that there did indeed occur in that year in Binghamton epidemics of measles and diphtheria and an unusual number of deaths from phthisis. These, however, explain only one-third of the excess of the rate for this year over the average rate for the following three years. In short, we have been unable to arrive at a satisfactory explanation of the irregularity of the total death-rate curve since 1902. We have nevertheless included Binghamton in

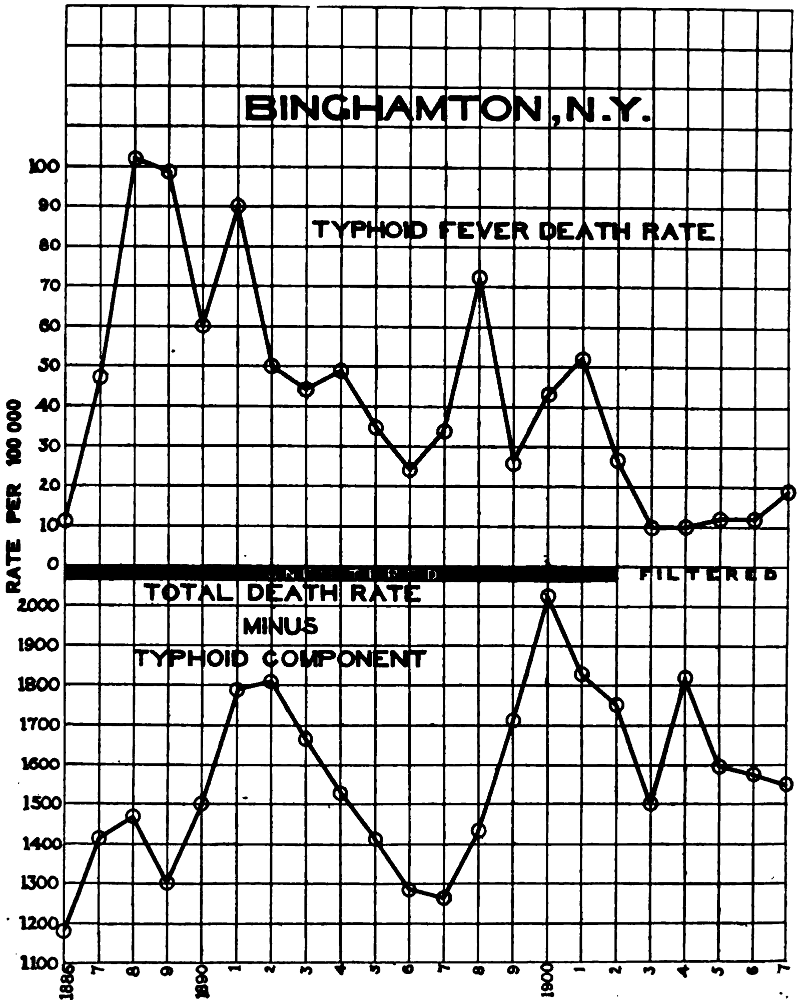

Chart 10.

our studies as an example, tho not a very clear one, of the Mills-Reincke phenomenon.

Taking periods of five years before and after filtration, we compute that for one death less from typhoid fever afterward there were 1.5 fewer from other causes—this being merely an uncorrected ratio not applicable directly as a test of Hazen's theorem.

3. *Watertown, N.Y.*—As a city which had suffered severely from typhoid fever and which, after a noted epidemic in 1904, had installed a mechanical filter plant, we were led to study *in absentia* Watertown, N.Y. In the foregoing section we have presented an atypical instance of the Mills-Reincke phenomenon, and we now submit a demonstration of a city where that phenomenon did not apparently occur at all after the filtration of the public water-supply.

Until 1904 Watertown took its water from the Black River, a stream polluted by the populations of a number of towns above. In September, 1904, mechanical filtration was introduced immediately following the famous typhoid fever epidemic studied and reported upon by Dr. George A. Soper. A comprehensive description of the city and its past and present water-supply is given in Dr. Soper's paper "The Management of the Typhoid Fever Epidemic at Watertown, N.Y., in 1904."[1]

We present herewith certain vital statistics for this city:

TABLE 20.
VITAL STATISTICS OF WATERTOWN, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:					
1880	†10,697				
1888	13,919	7	50	294	21.1
1889	14,322	4	28	224	15.6
1890	14,725	6	41	234	15.9
1891	15,422	6	39	285	18.5
1892	16,119	8	50	371	23.0
1893	16,816	9	54	336	20.0
1894	17,513	15	86	312	17.8
1895	18,210	31	170	331	18.2
1896	18,907	9	48	312	16.5
1897	19,604	12	61	340	17.3
1898	20,301	19	94	291	14.3
1899	20,998	18	86	351	16.7
1900	†21,696	22	101	397	18.3
1901	22,446	8	36	347	15.4
1902	23,196	15	65	317	13.7
1903	23,946	17	71	356	14.9
1904	24,696	52	211	413	16.7
After:					
1905	‡25,447	6	24	384	15.1
1906	26,197	13	50	461	17.6
1907	26,947	10	37	504	18.7

* Compiled and computed from Reports of N.Y. State Dept. of Health.
† U.S. Census. ‡ State Census. Other population figures interpolated by the "arithmetical" method.
Mechanical filter since September, 1904.

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[1] *Jour. N.E. Water Works Assn.*, 22, p. 87.

For Watertown as for Binghamton we have plotted the general death-rate and that from typhoid fever (Chart 11). The irregularities in both curves are even more evident than in the case of Binghamton. Typhoid fever was apparently not reduced by the introduction of filtration to as low and as permanent a level as should have been expected, for in 1906 we find that the rate had again risen to 50. The total death-rate minus typhoid component, instead of showing a decrease in 1905, 1906, and 1907, actually shows a rapid rise. Here, then, we find apparently the direct reverse of the Mills-Reincke phenomenon, and this fact requires explanation. The authors have been unable to undertake any complete and personal investigation of the local conditions, but may venture to point out briefly several factors possibly of importance.

As in the case of Binghamton, we must regard as suspicious the great irregularities of the curves. Even at certain times of high epidemic prevalence of typhoid fever—notably in 1904, and also in 1895 and 1898—the total death-rate remained at a comparatively low level; while the highest total death-rate shown on the diagram occurred in a year (1892) when typhoid fever, tho excessive, and not reached nearly the proportions of later years. These fluctuations are undoubtedly due in part to the small numbers dealt with, for in a population of only 21,696 (for 1900) the small number of deaths each year leaves much room for serious percentage fluctuations. This circumstance, however, can hardly furnish more than the beginning of an explanation.

A much more important fact in connection with the non-appearance of the Mills-Reincke phenomenon is that the typhoid fever death-rate itself was not reduced after filtration to nearly as low a level as would have been expected. Even after nearly two years from the beginning of filtration, we find a rate of 50 (in 1906), while for 1907 and 1908 (figures for the latter year just published) the rates were 37 and 40 respectively. These rates throw a strong suspicion on the efficiency of purification, and if a considerable amount of infection still remains in the filtered water, the Mills-Reincke phenomenon ought not to have been expected to appear. This point we wish to emphasize particularly, for, if the excess of typhoid fever in Watertown in 1906–8 was due to the water, that fact would

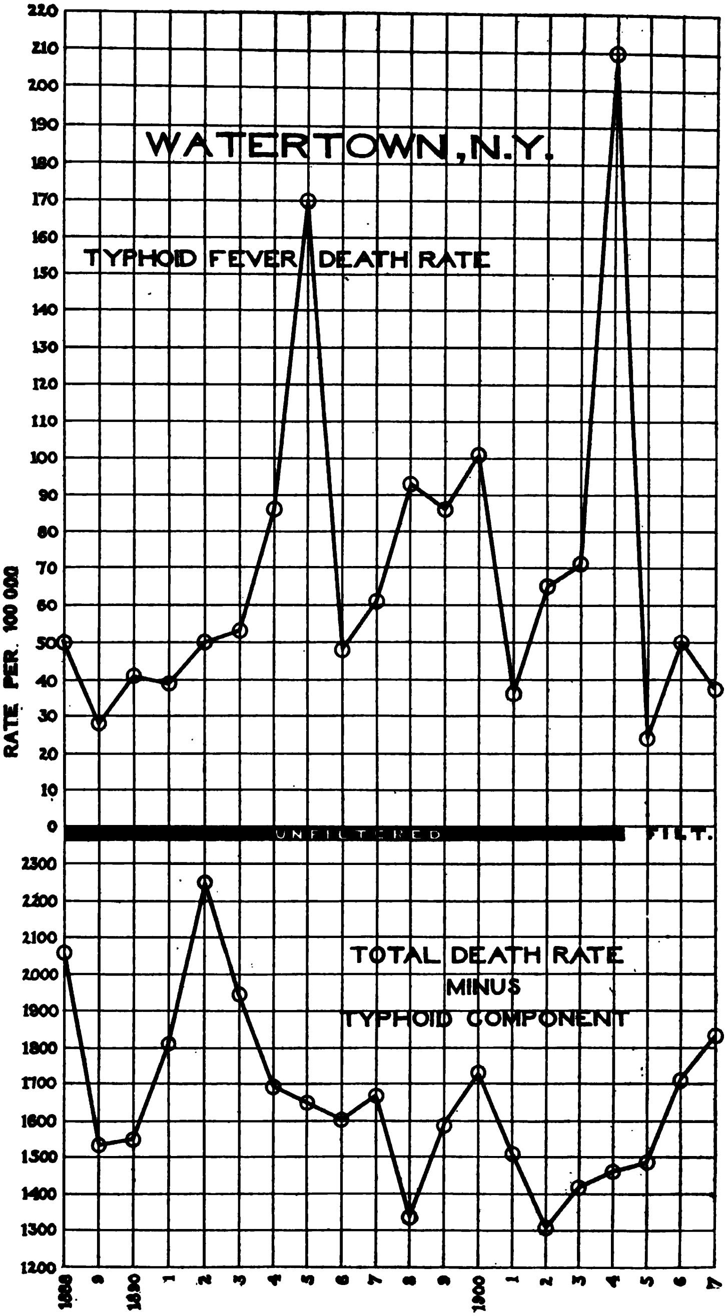
WATERTOWN, N.Y.
TYPHOID FEVER DEATH RATE
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
RATE PER 100 000
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
UNFILTERED
FILT.
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1888
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5
6
7

CHART II.

afford sufficient reason for the absence of the Mills-Reincke phenomenon.

We understand that acids or other chemical substances in the waters of the Black River have at times, especially of low water, been present in sufficient concentration to interfere with the proper operation of the city filters. Evidence of such chemical pollution is not far to seek.

> It is from the pulp and paper industries which have become well established on the river that the present gross pollution of the river is due. A number of mills are situated on the watershed with an aggregate output of over 300 tons of paper per day, in the manufacture of which sulphite pulp is used. Watertown is an active manufacturing city, and the river shows unmistakable signs of a high degree of pollution. All kinds of refuse are thrown directly into the stream, the paper mills and other factories using water in abundance to carry out factory wastes (Monthly Bulletin, N.Y. State Board of Health, July, 1908, p. 190).
>
> The effect of the chemical waste is quite apparent in times of low water in the river. A change of color of 25 parts per million (platinum scale) in four hours is not unknown here. . . . . This color change is frequently accompanied by a decrease in the alkalinity of the raw water (F. H. Jennings in discussion of above-mentioned paper by Dr. Soper, p. 137).

It may be objected that if there were sufficient concentrations of chemical wastes in the river to interfere with the operation of the filters, most or all of the bacteria in the water would be killed by their disinfecting properties, for there is no doubt that such wastes as those from pulp mills have a marked germicidal effect.[1]

But it is probable that the composition of the water fluctuates widely and rapidly, as is asserted in one of the above quotations, and it is quite conceivable that water of high disinfecting powers with low bacterial content today might incapacitate the filters for dealing with water of low disinfecting power and high bacterial content tomorrow.

XVIII. FLUCTUATIONS OF POPULATION IN PERIODS OF PANIC AND PROSPERITY AS SOURCES OF STATISTICAL ERROR.

Very early in our studies we were struck with the fact that the beginnings of filtration in Lawrence and of substitution of groundwater at Lowell coincided almost exactly with the panic of 1893, and the question naturally arose as to whether the diminished death-rates observed might not have been due, wholly or in part, to the influence of the panic. Our attention was first drawn to this important matter by newspaper references touching the effect of hard times upon health, particularly by an editorial in the Springfield (Mass.) "Republican" of June 30, 1908, from which it appeared that hard times are accompanied by a marked improvement in the public health. Corollaries were drawn to the effect that such improvement was doubtless due to less overworking, less overeating, less overdrinking, and the like—in short, to saner and more wholesome methods of living. And, certainly, following the period of financial depression in the United States setting in late in 1907, unusually low death-rates have been reported from many American cities. An article which has come to our notice, "Era of Low Mortality Reached by the Civilized World,"[1] states, for example, that for 1908 the death-rate for the registration states was, according to the U.S. Census, only 15.3 per 1,000 of population, this being, according to Dr. C. L. Wilbur of the Census, "probably the lowest death-rate that has ever occurred in the United States."

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[1] See M. O. Leighton, "Prelim. Report on the Pollution of Lake Champlain," *Water Supply Paper No. 121, U.S. Geol. Survey, 1905*, Report of E. B. Phelps, p. 111. Also E. B. Phelps, "Pollution of Streams by Sulphite Pulp Waste," Paper No. 226 of *ibid.*, p. 7. Cf. *Penn. Health Bull.*, November 1909, on "The Germicidal Effect of Water from Coal Mines and Tannery Wheels upon Bacillus Typhosus, Bacillus coli, and Bacillus anthracis."

Our attention was independently drawn to the possibility of such an explanation as above mentioned of the lower death-rates at Lawrence by an employee connected with the registration of vital statistics in that city, who stated that to his personal knowledge there had taken place there, at the time of the panic of 1893, a marked change in the habits of the people, who began to spend more time in the open air, to make excursions into the country, and in general to live in a more leisurely and healthful manner. The new mode of life thus imposed upon the people was, it was argued, continued by force of habit even after the mills had again resumed full operation, more vacation time being then demanded by the employees. In the same discussion it was asserted also that there was a considerable change in the character of immigration at this time. It is, in fact, common knowledge among persons familiar with conditions in industrial cities that such phenomena do take place to a greater or less extent in hard times, with reverse effects in times of prosperity; and lower death-rates certainly have appeared in some cities at times of industrial depression.

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[1] *Boston Med. and Surg. Jour.*, November 4, 1909.

On the other hand, there is good reason for believing that the simplest and often the chief explanation of the diminutions in the *computed death-rates* will be found in a temporary decline in industrial urban populations. In such case estimated populations for intercensal years would be inflated over their true values, and the rates based upon them would give false evidence of improvement in the public health. Thus there may be in many cases a considerable error which would be made manifest if annual, instead of quinquennial, or decennial, censuses were taken. This would of course be true of the U.S. Census method of estimation (used by us throughout), which gives for such cities, regardless of such possibilities, the same absolute increment from year to year between any two censuses.

To any objection based on a supposed effect of the panic of 1893 on the death-rates of Lawrence and Lowell—either through actual betterment of the public health or through diminished population—we answer first of all by calling to mind Manchester, N.H., a city in all important respects similar, which we have taken as a norm. Some influence upon the death-rates of Manchester, as of other cities, during the hard times might have been expected, but the fact is that no such influence is discernible in the figures. This indicates that the rates for Lawrence and Lowell remained uninfluenced from that source.

Altho satisfied that the results of our studies on Lawrence and Lowell are exonerated by the Manchester data from any serious blame on either of these points, we have thought desirable, nevertheless, to bring forward certain explanatory and confirmatory evidence, particularly in regard to possible diminutions of population in periods of panic. And in doing so we shall include also the case of Hamburg, where a panic was caused by the Asiatic cholera epidemic of 1892.

The cholera panic at Hamburg resulted in a temporary check to the growth of the population such as might be expected from an industrial panic. In fact, not only was the growth checked, but for a time the population was actually diminished, as observed by Dr. Reincke:

> While the population of Hamburg has in recent decades increased regularly by at least 2.6 per cent per annum . . . . it has in 1892 not only failed to increase but has actually decreased by 2,808 persons. . . . . Immigration into the city, which already

at the beginning of the year was small, ceased entirely after the outbreak of the cholera, while emigration increased correspondingly ("Bericht des Medizinal-Inspektorats für das Jahr 1892," Hamburg, p. 1).

The observation thus recorded by Dr. Reincke would have been impossible without accurate statistics for the population from year to year, and we find that such statistics were in fact afforded by annual enumerations of population.

> In those years in which no censuses have taken place the Statistical Bureau of the Tax Commission has made since 1868 in the city and suburbs . . . . inquiries on population and dwelling conditions, including all data necessary for official purposes ("Statistisches Handbuch für den Hamburgischen Staat," 4te Ausgabe, Hamburg, 1891, p. 24).

This inquiry, made December 1, commonly called *Umschreibung*, approximates ever more and more the exactitude of the more detailed quinquennial census. Data are taken as to name, age, occupation, etc. The results are not, however, usually worked up in much detail.[1]

We call special attention to the fact that the death-rates given in Dr. Reincke's Annual Reports as well as in the "Sanitary History of Hamburg" (from both of which works we have in this paper freely quoted and drawn data) are based upon these annual enumerations of population.

Without further comment we present the results of the annual enumerations in the following diagram, based on figures taken from the "Sanitary History of Hamburg," p. 28. The dotted lines indicate for comparison the error which would have been introduced had there been only quinquennial or decennial censuses, with interpolation of the other years by the "arithmetical" or U.S. Census method. The maximum error due to this method would in this case have been with the quinquennial only 2 per cent, with the decennial 4 per cent.

It is evident that the recovery of population set in soon again after the panic of 1892–93, and was very rapid.

Turning next to Lawrence and Lowell and the question of the effect of the industrial panic of 1893 in diminishing the population growth of those cities, we have evidence that in them, as in Hamburg after the cholera scare of 1892, recovery in general public confidence

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[1] Cf. Reincke, *Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert*, p. 312.

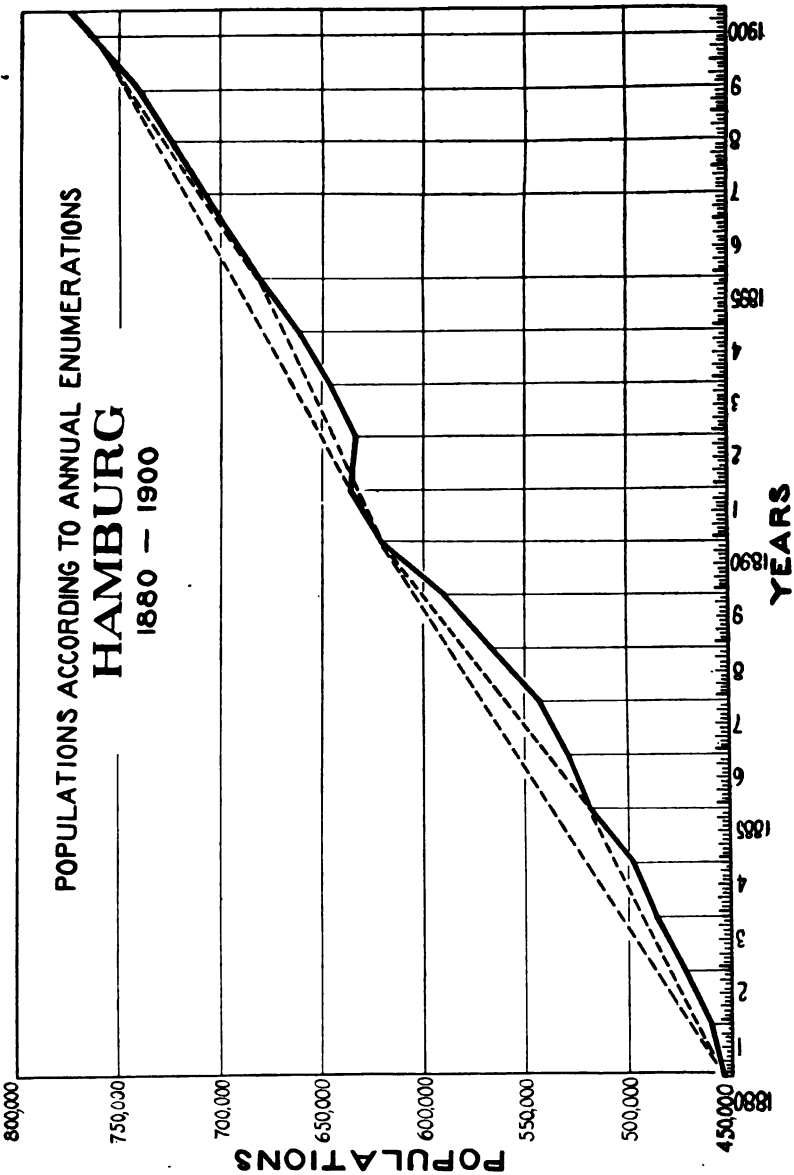
POPULATIONS ACCORDING TO ANNUAL ENUMERATIONS
HAMBURG
1880 — 1900
YEARS
1880
1
2
3
4
1885
6
7
8
9
1890
1
2
3
4
1895
6
7
8
9
1900
POPULATIONS
450,000
500,000
550,000
600,000
650,000
700,000
750,000
800,000

CHART 12.

and prosperity (with their corollary, increase of population) was early and rapid. There is first of all indication of this in the general financial and industrial movements in the United States at this time.

> Past experience has produced a number of instances where, in the second year after a great financial panic, business recovery went ahead so rapidly that it was found necessary, in the next year, to slow up. Of this the classic case in point was 1895. . . . . Sudden revival; active buying of merchandise; prediction of another "boom time"; spectacular rise in stocks, with Europe's capital enlisted; iron production surpassing all monthly records—these things were witnessed in the second year after 1893 ("The Nation," "Finance," February 24, 1910).

And this description is confirmed by the populations for Lawrence and Lowell given by the State Census of 1895. The characters of the populations had also, according to this census, remained practically the same.[1] Thus any fluctuations in quantity or character of population which may have taken place in 1893–94 were chiefly temporary. And certainly the much diminished death-rate computed for 1895 cannot be ascribed in any significant degree to error in the population statistics employed.

As an approximate indication of year to year fluctuations of population in Lawrence and Lowell, we have obtained, by courtesy of their city assessors, the total number of polls in those cities (enumerated for purposes of taxation), including practically all males over 20 years of age, as of May 1 of each year since 1889. These figures we have plotted in the following diagram, together with the total populations estimated by the so-called arithmetical method.

The panic and hard times of 1893–94 and the industrial depressions of 1903–4 and 1907–8 are seen to be clearly reflected in the curves for polls. The extent of fluctuation in these cities about 1894 was apparently somewhat greater than at Hamburg in 1892 and the following years. The indication from the Census of 1895 that the check to increase of population in 1893–94 was merely temporary, is confirmed. There was apparently also a check to growth of population in both cities following 1896, and this may perhaps be explained as a result of the secondary industrial depression which followed the revival of 1895.

The ratio of polls to total population remained fairly constant in both cities for the four census years, though more nearly so for

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[1] Cf. sec. xv.

Lawrence than for Lowell. Thus for Lawrence in 1890 there were 3.88 persons in total population to each poll; in 1895, 3.69; in 1900, 3.82; and in 1905, 3.84. For Lowell the corresponding figures are

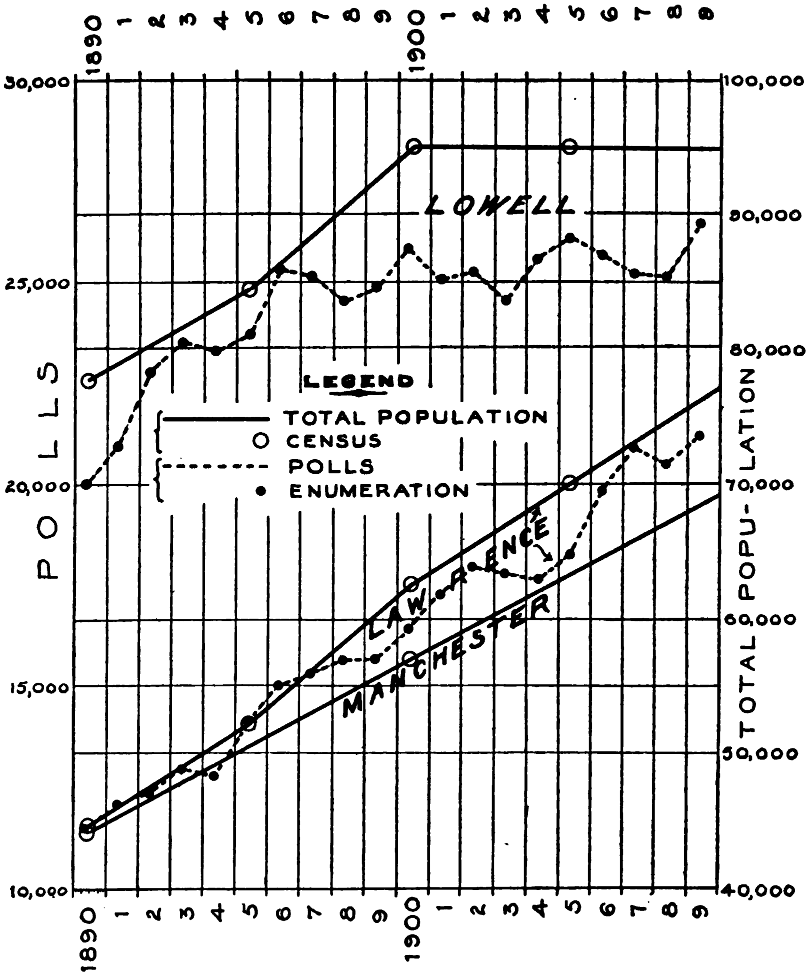

CHART 13.

3.88, 3.56, 3.68, and 3.64. These ratios afford a rough check on the accuracy of the poll enumerations, which tho of uncertain reliability, appear to be sufficiently accurate for the present purpose—i.e., an approximate indication of fluctuations of population.

In 1905 there was a diminution of the population of Lowell not paralleled at Lawrence, a difference which we have left without investigation as being unessential to our study.

We finally conclude, as to fluctuations in magnitude and character of population as sources of statistical uncertainty, that in particular years, especially where only a decennial census is to be had, errors seriously impairing the accuracy of death-rates computed from estimated populations may be introduced. The indications, however, from the curves just given, that the populations of Lawrence and Lowell had in 1895 recovered much of their former growth energy in spite of year to year fluctuations, taken with the evidence given in sec. xv on the elements of the populations and in secs. xv and xvi on Manchester as a norm, lead to the conclusion that no error seriously affecting our results can be attributed to fluctuations in magnitude and character of population.

XIX. SUMMARY AND CONCLUSIONS.

We may now bring together the various results of our study, as follows:

There is abundant evidence of the occurrence of the Mills-Reincke phenomenon, not only in the vital statistics of the cities of Lawrence and Hamburg, studied by Messrs. Mills and Reincke, respectively, but also for Lowell, Albany, and Binghamton. The phenomenon seems at first sight to be wanting in Watertown; but it is possible that in Watertown the purification of the public water-supply has been as yet relatively imperfect, and it is interesting to note that under these circumstances no diminution of the general death-rate has as yet occurred. For a fuller discussion of this point we must refer to the body of the paper.

We have not extended our studies over a larger range of cities, partly for the reason that trustworthy statistics for American cities are by no means common, and partly because of the incomplete and unsatisfactory character of investigations carried on at a distance. We earnestly hope that students of sanitary science who may fortunately have access to the necessary data for other cities will not fail to study and report upon the problems here raised. It is also greatly to be desired that similar studies should be made on the data afforded by such cities as Washington, D.C., in which the filtration of the public water-supply has not been followed by any material decline in the death-rate from typhoid fever; for in this case such filtration would not be expected to have produced any material decline in the total death-rate. Whether or not a partial purification of a public water-supply may be expected to be followed by a moderate decline in the total death-rate we cannot say, but the experience of Watertown would seem to indicate that this is not necessarily the case.

Mr. Hazen's quantitative expression for the Mills-Reincke phenomenon, when applied to the cities which we have studied (with the exception of Watertown), appears sound and conservative. It seems likely, however, that it will be impossible in the future to confine the relation even within the broad numerical limits suggested by Mr. Hazen. In fact, Mr. Hazen himself is very careful in this particular, as will be seen by a reference to his original statement (p. 510). It is probable that the pollution of a public water-supply may consist, at one time or in one place, of much typhoidal infection mingled with comparatively little sewage, or on the other had, of much sewage only lightly charged with typhoid fever germs. In the former case the reduction in typhoid fever might be out of all proportion to the reduction in general death-rate, and in the latter case vice versa. For Hamburg we have pointed out above that the saving in typhoid mortality was slight in comparison with the saving of mortality in other diseases combined, i.e., roughly only *ca.* 1 to 16. In the other cities studied we find ratios widely different from this, e.g., at Lawrence, 1 to 4.4, at Lowell 1 to 6.0, in Albany, *ca.* 1 to 4.1 (uncorrected), and in Binghamton only *ca.* 1 to 1.5 (uncorrected). It is clear, therefore, that Hazen's theorem is merely a convenient formula rather than a precise mathematical expression.

One of the most surprising results of our study will probably be the disclosure of the remarkable relation subsisting between polluted water and infant mortality. This subject has been more fully elucidated by Dr. Reincke than by anyone else, as will be evident from a perusal of his discussions quoted above. Our graphical demonstrations, however, are worthy of notice, as they bring out strikingly the principal facts. Students of preventive medicine will do well to extend these studies, which promise to shed much light upon the solution of one of the most serious problems of the time.

Closely associated with infant mortality stand diarrhea and gastro-intestinal disorders (90 per cent of which in Hamburg occurred among infants under one year of age) in relation to polluted water, which now bids fair to assume a causal importance in these diseases second only to that of contaminated milk.

In regard to tuberculosis the evidence, tho less striking, is interesting and suggestive. Inasmuch as we have been unable, even after the most careful investigation, to discover any other possible explanation of the figures, we are forced to the conclusion that a considerable portion of the decline in mortality from tuberculosis in Lawrence and Lowell during the years immediately following a change from polluted water-supplies was due to that change; and in line with this conclusion a similar explanation appears more than probable for Hamburg.[1]

For pneumonia, bronchitis, and the remaining infections, our data and diagrams speak with clearness, and we need not repeat the discussions we have already given in the preceding sections.

We have examined in detail the influence of fluctuations of population upon our statistical results, and find that no serious error has been encountered by us in that direction. It is certainly an interesting fact that the great panics have rarely if ever coincided with either federal or state censuses; but we find no reason to believe that the declines in either typhoid fever or the general death-rate in Hamburg, Lawrence, or Lowell, altho these happened to coincide with periods of panic, were in fact attributable to decrease of population.

Finally, the question naturally arises, to what is the decline of mortality observed in the Mills-Reincke phenomenon for diseases other than typhoid fever due? A little reflection will show that increase of vital resistance, due perhaps to the use of a purer drinking water, might produce this effect, while, on the other hand, the same results might be reached by an exclusion of disease germs formerly present and working upon the bodies of their victims. Or, as a third possibility, the phenomenon might be due to a combination and co-operation of these two factors.

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[1] See p. 185 of our paper in the volume *Tuberculosis in Massachusetts*, mentioned on p. 491 above.

It is interesting to observe that Mr. Mills in his writings upon this subject, without especially committing himself to either hypothesis, has apparently had in mind chiefly an increase of vital resistance, while Dr. Reincke has expressed himself rather as looking to the removal of disease germs previously present.

The facts at present in our possession do not allow us to settle the question beyond peradventure, and this problem, like many others raised throughout our paper, requires further elucidation.

THE FOUNDATIONS OF PREVENTION.

By William T. Sedgwick, Sc.D., of Boston, Professor of Biology, Massachusetts Institute of Technology.

One of the great characteristics of living things is their property of interfering with nature. Lifeless things may be said to submit tamely, helplessly, and mechanically to their surroundings, while living things even in the lower orders of life, react, resist, respond, and otherwise refuse to obey in a purely mechanical fashion the demands of their environment. The very idea of interference by lifeless things with the regular phenomena or laws of nature seems absurd. Rain, mist, fog, frost, not only obey natural laws but yield themselves without special resistance to gravity, electricity, heat and cold. The simplest living things, on the other hand, may struggle against gravity, move toward or away from heat or light, and, while in the larger way necessarily obedient to the laws of nature, are still in regard to these capable of special and irregular behavior. When, therefore, we find the objection raised, as it sometimes is raised, that preventive medicine is an interference with nature and natural law; that the prevention of infant mortality is likely to lead to race weakness; or when we encounter other superficial if not thoughtless criticisms concerning some of the most promising features of modern life, we shall do well to dig down to the foundations and to inquire What, after all, is the philosophy of prevention? Does the prevention of poverty lead to idleness, the prevention of premature death to overpopulation, the prevention of crime to the production of mollycoddles? We hear much of natural law and respect for natural law, and we do well to give heed to these things, but we must be careful not to confound obedience to natural law with a servile and unresisting submission to things as they are. Let us, on the other hand, inquire how things as they are came to be and whether a general conformity to natural law is not consistent with self-assertion and those more individual phenomena of life which gives it variety, spice and charm.

We may then begin at the beginning and examine somewhat carefully the foundations of interference with nature and natural law, one form of which is prevention of infant mortality, another the prevention of poverty, another the prevention of crime, another the prevention of disease. As we have said already, it is characteristic of lifeless bodies that these obey implicitly, mechanically and completely the established laws of nature, and follow in their fashion existing conditions. We have cited as an example the behavior of the various forms of water, and a similar mechanical obedience may be observed in the sands of the sea, in the gases of the atmosphere, in the clouds, and so far as we know in the heavenly bodies. These, to be sure, possess the universal property of inertia and accordingly exert a kind of passive resistance to change of every sort. But inertia is the most impersonal, the most inorganic, the most typically lifeless, because the most helpless, phenomenon in nature, and the resistance offered by inertia is simply involuntary obstruction to displacement, and opposition to change of every sort.

With this implicit, mechanical obedience to nature goes, it is true, a calmness, a quietism, which has excited the envy of the poets:

"And a look of passionate desire
  O'er the sea and to the stars I send;
Ye who from my childhood up have calmed me,
  Calm me, ah, compose me to the end."

When, however, we turn away from the inorganic world to the lowest forms of life—protozoa or protophytes—we enter another region. Living organisms, while necessarily obedient to the larger laws of nature and strictly conditioned by temperature, gravity, light and other fundamental phenomena, show, nevertheless, important reactions, responses, movements and other properties through which they actively resist, and may even refuse to obey, the less imperative calls of their environment. And as we rise in the scale toward higher plants and higher animals, we find a constantly greater and greater tendency not to yield passively to environment, typified at its best and largest in men like Tennyson's Ulysses:

"Made weak by time and fate, but strong in will,
To strive, to seek, to find and not to yield."

This tendency often amounts to an actual control of many elements of environment by living things in their own interest, and it is worth while to observe, in passing, that competition and the struggle for existence arise in large measure because of this tendency toward controlling environment, for if all organisms should weakly yield to the things about them, there would be no "struggle" for existence and, because all would be doing the same things, no active competition.

Herein also lies the weakness of the doctrine of *laisser faire*, which virtually assumes that interference with human nature should be avoided or at least minimized. But to let nature wholly have her way is to revert to savagery; and while self-development is perhaps the highest form of development which we know, it is by no means so common or so certain as to make unnecessary frequent altruistic interference, or even social regulation.

With the theory of prevention in general thus in mind, we may pass on to its illustration by examples. And first let us glance for a moment at a form of prevention which finds everywhere universal acceptance, *viz.*, the prevention of crime. The prevention of murder, or the theft of life, of robbery, or the theft of property, and of assaults of every sort harmful to the the other hand, the prevention of waste has never yet come to police power is invoked and they yield to social control. On individual fails to abate those for which he is responsible, the isms. So, also, it is with the prevention of nuisances. If the their application, they have become not merely truths but tru- control—or both. And since no one questions these ideas or or the substitution for this of the police power—that is, social person require either the promotion of individual self-control be recognized as amenable to social control, and unless the individual seeks to compass it—as in America he generally does not—nothing is done. Midway between the prevention of crime and the prevention of waste stand such forms of prevention as that of disease, in which the individual is expected to do most, but the police power some, of the work—the proportion expected from each varying with the disease to be prevented.

If this happens to be small-pox, social regulation is all-powerful to enforce vaccination, isolation, quarantine and the like. If the disease be typhoid fever social control is slight and individual control paramount. And when we come to infant mortality, the police power and other forms of social control have been, until very recently, almost negligible. This Conference, however, and others like it in other countries, are good evidence that a change is at hand. It has become almost —but not yet quite—as intolerable that infant life should be ruthlessly wasted, as that the glycerine which was formerly a by-product lost in soap-making, should continue to be thrown away.

No one who has watched the rearing of a family of young birds in a nest, perhaps about his own home, can have failed to observe the pains taken by the parent birds to secure protection, first against natural enemies, such as rain, wind and cold, and second against living enemies such as predatory birds, squirrels, cats, and the like. Now this is essentially prevention of infant mortality and it consists in an interference with natural laws which would otherwise ruin the nest or destroy the eggs or young birds. Most of the adaptations which are so characteristic of living things, such as the fall of the leaf in the autumn, and the blossoming of plants in the spring, are examples of the refusal of living things to obey without resistance the laws and phenomena of nature. And nowhere is this more conspicuous than in the devices adopted by plants in temperate zones for keeping alive during the winter those seeds or spores which without these protective devices would otherwise perish in the winter cold. Protective coloration, mimicry and the like are other forms of defense designed to prevent either infant or adult mortality which without these would be the inevitable consequences of the working of natural law.

The foundations of prevention are, in fact, as broad as biology itself. Prevention, inhibition, interference with natural phenomena are all characteristic of life, and the less our submission to environment, the greater our interference, the more complete our control, the higher is our development—the more notable the progress of civilization. It has been objected by

Pearson that the prevention of child labor is likely to lead to race suicide. It has been objected by others that the prevention of infant mortality will have the opposite effect and—assumption upon assumption—it is assumed in both cases that these consequences are obviously pernicious. We may, however, reasonably doubt both of these theorems and their corollaries, for it clearly is not safe to dogmatize in this matter, because no one has yet proved that race control—the so-called "race suicide"—is necessarily disadvantageous, or that the prevention of infant mortality is unwise. Instinctively, we feel that such control and prevention are prevention desirable, and if we ask for justification for them, it is not hard to find, along the lines already indicated.

What then shall be our mechanism of the prevention of infant mortality? Is it not, first, protection against, by interference with, natural conditions—just as birds build their nests for shelter against weather and against their enemies; and, next, feeding, such as shall comfort, support, develop, and cheer; and then police guardianship against vagrant infectious disease; and finally, and best of all, intelligent parentage? Let us examine somewhat carefully each of these foundation stones in the general structure of scientific prevention.

We have all heard of the "exposure" of infants, a term which describes a hideous practice in certain Asiatic countries, under which infants deemed superfluous are left to the non-human care of nature and speedily perish, exposed to weather, wild beasts, or whatever conditions may happen to surround them. In most cases, however, even among savages, some shelter is immediately cast about the new-born child, even if this be no more than that of the wigwam, the tent, a piece of clothing, or other rudimentary appliance. And going to the other extreme, we know how complete in the best ordered homes of to-day is the protection immediately thrown about the new-born child, only to be continued and, if possible, perfected during the first few months of infant life. Care of this sort has long been given among the well-to-do even in the prenatal period, and a movement now on foot in Boston provides it for some who would not otherwise have had it.

The Women's Municipal League of Boston, according to one of its officers, Mrs. William Lowell Putnam, chairman of the Committee on Infant Social Service, "has begun with .... the mother ....

"Feeling that bad prenatal influences could not be too early cared for, the League is working with pregnant women quite as much as with babies .... Two nurses are employed, one giving her time to the pregnant women, the other to the babies and their mothers.

"The League is trying to see how many more babies may be healthily brought into the world and carried healthily through their first year by proper teaching of the mother, and also incidentally how many mothers' lives can be saved by preventive work with them."

When we come to the support and maintenance of the new-born child we see all sorts of care extended by the mother, from that best, though most primitive, form of maintenance, in which the mother surrenders to the child portions of her own body in the form of milk, up to the most elaborate incubator arrangements of modern times. In savage communities we get no further, but in the more highly civilized community interference with nature now also begins in the shape of police protection against infectious diseases, so that the new-born child shall be sheltered as far as possible from those various kinds of itinerant death which may roam through the community. Here we have the basis and in some cases the high development of Board of Health work, together with such forms of municipal sanitation as the control of street dust, the supply of pure water and pure fresh milk and the suppression of smoke.

And finally, or perhaps first of all, we have in men, and especially in highly civilized men, that intelligent interference with nature which can only be accomplished through intelligent parentage and the scientific supervision of infant life by wise and educated parents. Social control contained in official protection by authorized agents of the community, and family supervision brought about by intelligent parentage, are the two phenomena which ought to distinguish the best conditions from the worst. In the worst everything is left to unaided nature, in the best, nature is duly regarded but yet wisely interfered with, aided, and controlled.

And how shall we secure these two great foundation stones for our modern social structure? I know of no other way than by making biology, the science of life and of living, the beginning and the end of our educational endeavor. We have studied the skies and the stars; we have philosophized on man and his destiny; we have built machines to do our work and sky scrapers to work in; we have learned how to imprison men and how to kill them, in war and in peace; but we have not yet studied biology, or learned many of the most fundamental lessons of the science of life.

Discussion of infant mortality in the 18th century centered largely around infant damnation. In the 19th century it shifted to post-mortem salvation, but in the twentieth it is turning toward prevention. So long as one of the most powerful intellects of the 18th century—Jonathan Edwards—could affirm that infants, not of the elect, "are, in the sight of God, as young vipers," it was natural for mere common folk to contemplate an excessive infant mortality, not perhaps with satisfaction but at least with resignation.

The watchword of a scientific age is prevention. The prevention of waste, the prevention of poverty, the prevention of crime, the prevention of pain, the prevention of disease and the prevention of premature death, to-day are debated as never before. But scientific prevention, precisely because it involves more or less interference with nature, requires for its foundations the completest possible knowledge of nature—including human nature—and of natural law; and above all more careful studies in biology, the science which lies at the basis of all knowledge of life and health and death. We must have also more and better training in all sorts of applied biology, such as hygiene and sanitation and eugenics, and medical sociology before we can expect to interfere wisely with natural processes or to control successfully the blind forces—of nature at work about and upon and within us.

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A COMPARATIVE STUDY OF INTESTINAL STREPTOCOCCI FROM THE HORSE, THE COW, AND MAN.*

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INTRODUCTION.

THE first real clue to the systematic relationships of the streptococci was furnished by Gordon when he pointed out that these organisms could be separated into well defined groups by a study of their fermentative reactions in various carbohydrate media (Gordon, 1904; Gordon, 1905). Houston carried forward the application of Gordon's tests (Houston, 1905; Houston, 1906); and finally Andrewes and Horder (1906) founded upon all these results a rational classification of the genus into seven main types or species. The basis of their division was statistical or biometrical. It involved the examination of records of many individual cultures (1,200 in the case of the streptococci) and the study of the frequency with which various characters, or combinations of characters, occurred. Type centers, according to the statistical method, are defined by the occurrence of a large number of individuals with a given characteristic. These common types, among such variable organisms as the bacteria, may properly be considered as representing species, about which the rarer varieties are grouped.

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The chief characters of the species of streptococci thus defined by Andrewes and Horder are indicated concisely in the table below (Table 1). Strept. equinus is described as characteristic of the intestine of the herbivora. It was abundant in horse-dung and was the commonest form in the street air of London. All the other forms were primarily of human origin, Strept. mitis and Strept. salivarius from the normal throat, Strept. fecalis from the normal intestine, and Strept. pyogenes and Strept. anginosus from diseased conditions.

TABLE 1.

TABULAR CLASSIFICATION OF THE STREPTOCOCCI.
(Andrewes and Horder, 1906.)

SPECIES	CHARACTERISTICS								
	Milk Clot	Neutral Red	Saccharose	Lactose	Raffinose	Inulin	Salicin	Coniferin	Mannit
Strept. equinus	−	−	+	−	−	−	+	+	−
" mitis	−	−	+	+	−	−	+	−	−
" pyogenes	−	−	+	+	−	−	+	−	−
" salivarius	+	+	+	+	+	−	−	−	−
" anginosus	+	+	+	+	+	−	−	−	−
" fecalis	+	+	+	+	−	−	+	+	+
Pneumococcus	+	−	+	+	+	+	−	−	−

One of the most interesting practical points about this classification lies in the fact that all the six streptococci of human origin ferment lactose, while Strept. equinus, which Andrewes and Horder hold to be characteristic of the intestine of the herbivora, fails to do so. If a general distinction between human and animal streptococci could be demonstrated it would prove of much practical, as well as theoretical importance. Sanitarians are continually seeking, and seeking in vain, for some criterion by which sewage pollution of human origin may be distinguished from the surface wash of streets and agricultural land. The colon bacilli from the intestines of various warm blooded animals have been shown in many investigations—the latest and most exhaustive coming from Dr. Bettencourt's laboratory at Lisbon (Ferreira, Horta, and Paredes, 1908; Bettencourt and Borges, 1908*a* and 1908*b*)—to be identical. If the streptococci should prove to be characteristic it would greatly aid the water analyst.

The work of Gordon, and Andrewes and Horder, to which reference has been made, pointed to lactose as the best differential medium for distinguishing human and animal streptococci. These investigators showed clearly that a large proportion of streptococci of human origin ferment lactose while most of those derived from horse-dung or street air fail to do so. On the other hand Houston (1906) in the examination of cow-dung obtained widely different results. Eighty-five per cent of his cultures from this source fermented lactose; but their reactions in mannit, raffinose, and neutral red were somewhat characteristic. Mannit was fermented by 24 per cent of the human cultures and by none of the bovine strains; raffinose was fermented by 32 per cent of the human and by 74 per cent of the bovine cultures; neutral red was reduced by 39 per cent of the human strains and by none of those from cow-dung.

These results suggest that both the horse and cow have characteristic types of intestinal streptococci which differ from each other and from those commonly found in the intestine of man. Our object in the present investigation was to confirm this conclusion by the study of a new series of cultures from the three sources. In particular we wished to obtain quantitative results with regard to the amount of acid formed in various media. This aspect of the question has been ignored by all the English observers, who are content merely to classify their cultures as fermenting or non-fermenting. Recent studies of the Coccaceae as a whole have shown however that exact quantitative data are of much value in classification (Winslow, 1908). We chose dextrose, lactose, raffinose, and mannit as the carbohydrates to be tested. Dextrose serves as a type of the simple sugars which are fermented to some extent by almost all streptococci. Lactose and raffinose represent, respectively, the aldehydic and anhydric groups of sugars. Mannit represents the alcohols. Three hundred and two strains of streptococci, from human, equine, and bovine feces, were grown in broths containing these carbohydrates and the resulting acidity in each case was determined by titration. The results as analyzed below indicate definite and characteristic differences between the streptococci from the three species of animals.

Methods.—All the streptococci studied were isolated from fresh feces, collected in a sterile tin can with tight-fitting cover. Human feces were deposited directly in the can while horse-dung and cow-dung were taken from the stable floor within a few minutes after ejection. Streptococci were isolated from 15 samples of human feces, 12 samples of horse-dung, and 22 samples of cow-dung. In all cases care was taken to remove the outer layer of the feces and to take samples from the interior in order to avoid contaminations from stable floor or air.

The attempt was made at first to isolate the streptococci by inoculating a loop of feces into dextrose broth, incubating for various periods from 4 to 96 hours, and then plating on agar. This procedure is effectual in isolating streptococci from polluted water; but with feces it utterly failed in our hands. Spore-forming bacilli were found upon the plates or no growth appeared at all. It is probable that the streptococci were overgrown by other bacteria, perhaps by forms like B. acidophilus.

We therefore adopted the method of direct plating on agar without any preliminary enrichment whatever; and this proved generally successful. Two or three heavy platinum loopfuls of feces were well shaken up in 10 c.c. of sterile water and two or three loops of the resulting suspension carried over to a tube of melted agar. This was poured into a Petri dish and incubated at 37° for 24–48 hours. Agar streak cultures were made from minute round colonies on these plates and the appearance of these streaks after 24–48 hours at 37° was generally characteristic. Streaks showing a faint veil-like growth or a few dotted colonies or a thin line confined to the streak itself were almost always streptococci. In isolating the first 210 strains a microscopic examination was made. Smears were stained for 30 seconds with cold carbol fuchsin and cultures showing chains, pairs, or single cocci were accepted. In every one of these 210 cases the microscopic examination confirmed the conclusion based on the macroscopic appearance; and we are confident that the characteristic growth of the streptococci can be easily recognized by the experienced observer. Heavy growths on the streak always proved to be bacilli. Chromogenic, vigorously growing staphylococci were not found at all.

Streptococci were least easily detected on the plates made from cow-dung. The latter showed a great many small white colonies from which selection was difficult. Four out of five cultures streaked from cow-dung proved to be bacilli while not one out of five of the cultures isolated from horse-dung as streptococci failed to prove so.

A rough estimate was made of the total number of bacteria in one sample of each of the three kinds of feces, by plating high dilutions on agar, and incubating at 37° for 48 hours. The number of streptococci was estimated by isolating and identifying colonies which seemed characteristic. The sample of human feces showed an average of 8 million bacteria per gram of wet feces and 2,500,000 were streptococci. The proportion of streptococci is somewhat higher than that reported by MacNeal, Latzer, and Kerr (1909) who found that streptococci made up from 10 to 20 per cent of the total bacteria present. This is perhaps because MacNeal and his associates determined their total count by direct enumeration under the microscope, while our "total" is only the agar count at 37°. It is probable that most of the intestinal cocci grow on ordinary laboratory media, while we know that many bacilli and spirilla do not. In the sample of the horse feces we found an average of 3 million bacteria, of which nearly half were streptococci. This corresponds with our general experience of the high proportion of streptococci in equine feces. Cow-dung on the other hand showed in the sample examined an average of 100 million bacteria per gram of wet feces, of which 10 million were streptococci. This small ratio of streptococci (altho the actual numbers were high) explains the difficulty experienced throughout in isolating streptococci from cow-dung.

An interesting individual case was met with in the study of human feces, in which streptococci could rarely be found at all and in which all bacteria growing on ordinary media were present in comparatively small numbers. Altogether the feces of 11 different persons were examined and streptococci were easily isolated in 10 cases. From this one individual, 7 samples were taken and 67 plates were made by the usual method (a loopful or two from feces to 10 c.c. water and a loopful or two of water to a plate). Only 22 out of the 67 plates showed growth and but 6 showed streptococci.

By the methods described above 302 cultures of streptococci were obtained in all, 116 from man, 100 from the horse, and 86 from the cow. As soon as a streak proved positive it was inoculated into broth tubes containing the four carbohydrate media tested. These were incubated for 72 hours at 37° and then titrated. Five c.c. of the liquid in each tube was measured out into a graduate, mixed with 45 c.c. of distilled water, and titrated in the cold against $n/20$ NaOH, using phenolphthalein as an indicator. Blank titrations were made at the same time on sterile tubes of the same batch and their results subtracted from those obtained for the inoculated tubes. The media used were in all cases made up with one per cent Witte's peptone, 0.25 per cent Liebig's beef extract, and one per cent of the carbohydrate to be tested.

Positive acid reactions were generally associated with obvious appearances of growth in the form of profuse white sediment along the bottom and sides of the tubes. In a very few cases, however, acid was produced in tubes which appeared clear to the eye.

In the case of negative tubes, with no rise in acidity and no turbidity or sediment the lack of development might conceivably be due to a failure of inoculation. Great care was taken however to transfer as much of the cultures as could be carried on a platinum loop. The fact that obvious growth almost always occurred in the dextrose broth tubes shows pretty clearly that inoculation was not at fault. The contents of 49 of the clear tubes of various media were examined by plating out on agar. Three tubes showed many colonies, 15 showed 1 to 6 colonies, and 31 showed none. It may reasonably be assumed that in such cases the streptococci introduced had simply failed to develop and gradually died out on account of the lack of suitable carbohydrate pabulum, upon which these organisms appear to be highly dependent.

RESULTS.

The results of the individual titrations are given in tabular form at the end of the paper. The first column indicates the culture examined, and the second, the number of the sample of feces from which it was derived. The figures for acidity represent the difference between the value obtained for each culture and the value of an inoculated control incubated under similar conditions. The results are probably significant within 0.2 per cent acidity.

A clearer idea of the meaning of these results may be gained from an inspection of Table 2 in which they are grouped together into acidity-classes, and from Charts 1, 2, 3, and 4, which have been plotted from the values in Table 2.

Dextrose is fermented more or less vigorously by practically all the streptococci from human and equine feces, but the streptococci of man produce a markedly greater amount of acid than those from horse-dung. The mode for the human cultures lies between 3.6 and 4.0 per cent; that for the equine cultures between 1.6 and 2.0 per cent. The streptococci from cow-dung exhibit two distinct and clearly marked types, one forming about 2.0–2.5 per cent acidity, approaching the value of those from horse-dung, and the other group, of about the same numerical importance, forming no acid at all.

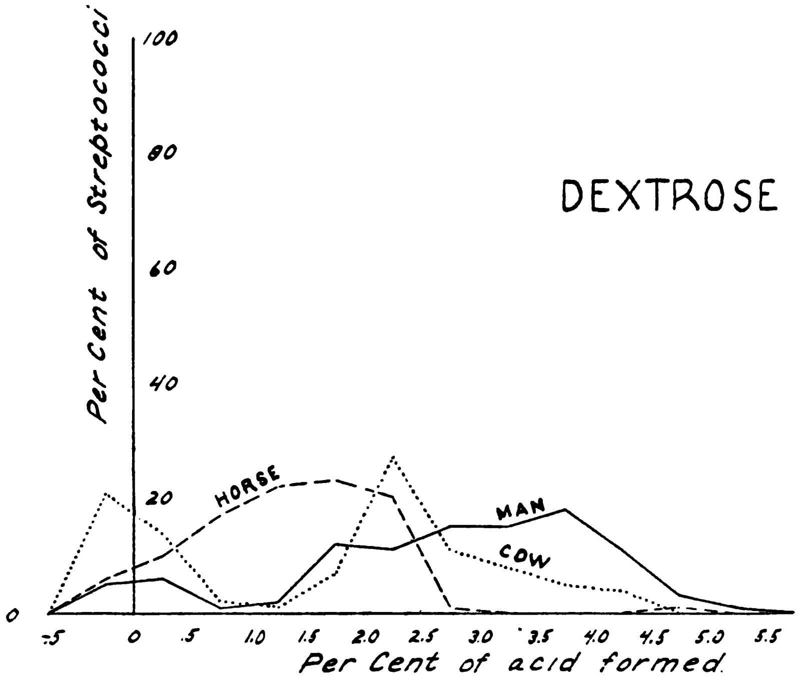

CHART 1.—Acid producing power of streptococci in dextrose broth.

In lactose the human and bovine cultures show two distinct types, one group yielding an acidity between 2.6 and 3.0 per cent, the other group producing no acid reaction at all. In the horse feces only the non-acid type is found.

Raffinose is not acted upon by any appreciable number of human or equine cultures. On the other hand, in the feces of the cow a small but clearly marked group appears, forming an acidity between 2.1 and 2.5 per cent.

Mannit is apparently not fermented by any important number of streptococci in the horse or cow but is acted upon by a small but definite group of the human strains.

TABLE 2.

STREPTOCOCCI GROUPED IN PER CENT ACIDITY CLASSES.

	−.5 0	.1 .5	.6 1.0	1.1 1.5	1.6 2.0	2.1 2.5	2.6 3.0	3.1 3.5	3.6 4.0	4.1 4.5	4.6 5.0	5.1 5.5
					Man (116)							
Dextrose......	6	7	1	2	14	13	17	17	21	13	4	1
Lactose.......	20	24	2	5	17	11	24	12	1	0	0	0
Raffinose.....	34	75	2	1	0	1	2	1	0	0	0	0
Mannit.......	47	36	6	4	12	0	1	0	0	0	0	0
					Horse (100)							
Dextrose......	6	10	17	22	23	20	1	0	0	0	1	0
Lactose.......	66	26	4	2	1	0	1	0	0	0	0	0
Raffinose	54	42	1	0	2	1	0	0	0	0	0	0
Mannit.......	62	36	0	1	1	0	0	0	0	0	0	0
					Cow (86)							
Dextrose......	18	12	2	1	6	23	9	7	4	4	0	0
Lactose.......	27	14	1	0	8	8	20	8	0	0	0	0
Raffinose.....	36	26	0	3	6	11	3	1	0	0	0	0
Mannit	54	27	2	3	0	0	0	0	0	0	0	0

These results are compared in a general way with those obtained by Houston (1905, 1906) and Andrewes and Horder (1906) in Table 3. In classifying our own results for this table we have considered all results under 0.5 per cent as negative. The various investigations are concordant with the exception that raffinose-fermenters in both human and bovine feces were less frequent in our observations than in those of Houston. Our results also indicate a somewhat lower percentage of lactose-fermenters. All the investigations show that streptococci from the human intestine generally attack lactose while some strains ferment mannit; bovine strains attack lactose or raffinose; and equine strains dextrose only.

TABLE 3.

COMPARATIVE RESULTS OBTAINED BY VARIOUS OBSERVERS IN REGARD TO FERMENTATIVE POWER OF INTESTINAL STREPTOCOCCI FROM VARIOUS SOURCES.

SOURCE OF FECES	OBSERVER	NUMBER OF CULTURES	PERCENTAGE OF POSITIVE RESULTS			
			Dextrose	Lactose	Raffinose	Mannit
Human..................	Houston	300	..	76	32	24
Human..................	Winslow and Palmer	116	89	62	6	28
Equine..................	Andrewes and Horder	13	..	0	0	0
Equine..................	Winslow and Palmer	100	84	8	4	2
Bovine..................	Houston	100	..	85	74	0
Bovine..................	Winslow and Palmer	86	65	52	28	6

In determining what types of streptococci are present in each species of animal, the correlation of fermentative power must be taken into account, as well as the activity of the organisms in each particular sugar. In the horse the problem is a simple one for all the organisms studied belong to a single type, characterized by a moderate acid production in dextrose broth and failure to attack either of the other carbohydrates. This is clearly the Strept. equinus described by Andrewes and Horder. In the human and bovine feces, on the other hand, the problem is more complex, and can best be understood by grouping the organisms according to their relation to all the carbohydrates studied, which has been done in Table 4.

TABLE 4.

INTESTINAL STREPTOCOCCI OF HUMAN, EQUINE, AND BOVINE ORIGIN, GROUPED ACCORDING TO THEIR FERMENTATIVE REACTIONS.

CARBOHYDRATE FERMENTED	NAME OF TYPE	PERCENTAGE OF STREPTOCOCCI FOUND IN		
		Man	Horse	Cow
None		9	15	18
Dextrose alone	S. equinus	23	73	27
Lactose alone		2	0	5
Dextrose and lactose	S. mitis	31	5	21
Dextrose and raffinose		0	3	3
Lactose and raffinose		0	0	12
Dextrose, lactose, and raffinose	S. salivarius	5	0	9
Dextrose, lactose, and mannit	S. fecalis	23	0	2
All four		0	1	3

One of the most striking results of this tabulation is the confirmation it affords of the reality of the type centers established by Andrewes and Horder. The strains which fermented no carbohydrates at all may be considered as weak forms which failed to establish themselves in any of the media. Aside from this class the only large groups of organisms were those named as type centers by the English observers, Strept. equinus, Strept. mitis, and Strept. fecalis. Strept. salivarius comes next; and the other combinations of characters are exhibited by so few strains that, with one exception, they may be considered as isolated variants from the commoner types. The single exception which may prove significant is the type fermenting lactose and raffinose but neither dextrose nor mannit, which made up 12 per cent of the fecal streptococci of the cow. If further study should confirm these results this type may deserve a specific name of its own.

Reviewing the results as arranged in Table 4 it appears that equine feces contain only one common type of streptococci, Strept. equinus, which attacks dextrose but cannot ferment the other carbohydrates.

In the streptococci of human origin on the other hand there are three common types. Of our 116 human cultures, 27 fermented dextrose only, 36 dextrose and lactose, and 27 dextrose, lactose, and mannit. The first type is clearly allied to Strept. equinus; but, while these streptococci exhibit the same general qualitative relations to the sugars in the horse and man, their vigor of fermentative power, when measured quantitatively, is somewhat different. The equine strains as pointed out above produce an acidity in dextrose of about 2.0 per cent and the same is true of the bovine forms. On the other hand the human streptococci produce almost twice as much acid. There is apparently a distinct variety of Strept. equinus characteristic of the human intestine which may be recognized by its high fermentative power as measured in dextrose broth.

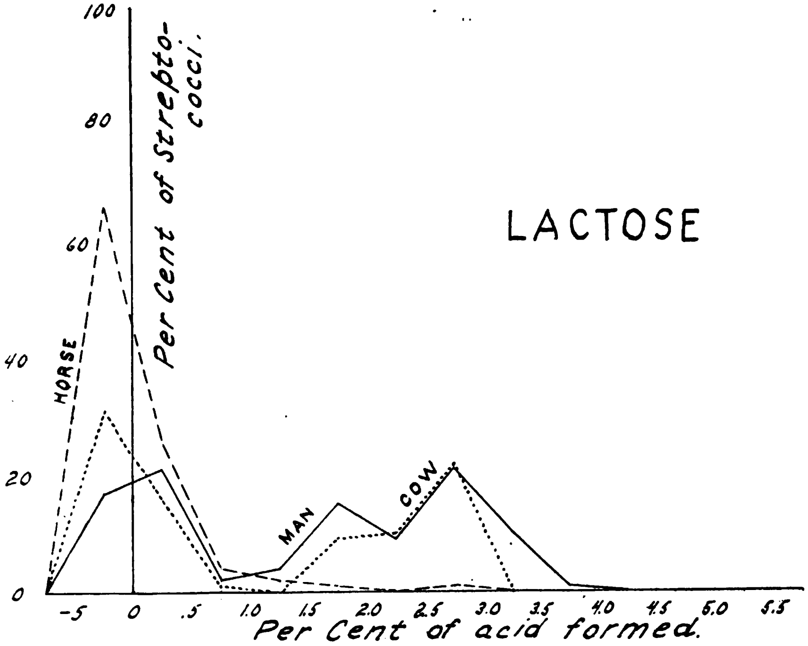

CHART 2.—Acid producing power of streptococci in lactose broth.

One interesting point about the non-lactose-fermenting streptococci of human feces, whether of the Strept. equinus type or of the group of weakened organisms which fermented neither sugar, was their association with diarrhea. We were especially anxious to see if characteristic streptococci were associated with this condition; and 8 of the 15 samples of human stools examined were more or less diarrheal in nature. Of 31 streptococci from normal stools, only 4 failed to ferment lactose; while of 85 strains from diarrheal stools 36 formed no acid from that sugar. Twenty-seven of the 36 fermented dextrose vigorously and 9 were weak forms which produced no acid in any medium. The 27 strains which fermented dextrose only form an interesting group differing, as noted above, in the amount of acid produced, from the type Strept. equinus. Twenty-four of these 27 organisms came from a single individual, appearing in three different samples of diarrheal stools. Altogether 47 strains of streptococci were isolated from these three stools; 24 of them were of the Strept. equinus type and 19 of the 24 formed more than 3 per cent acid in dextrose. The other three human strains of Strept.

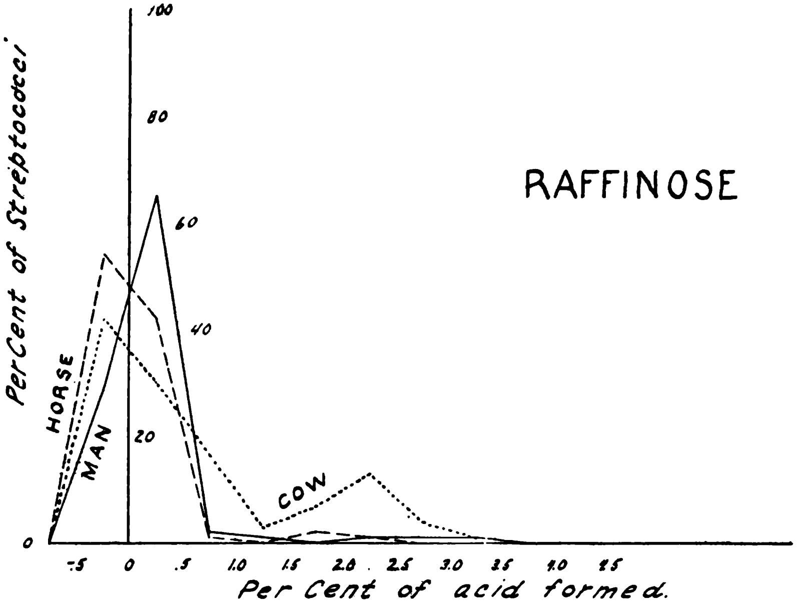

CHART 3.—Acid producing power of streptococci in raffinose broth.

equinus were from the diarrheal stools of other persons; and the connection may prove to be something more than a personal idiosyncrasy.

The second type of streptococci found in human feces, the first in point of abundance, was Strept. mitis, which ferments dextrose and lactose but not raffinose and mannit. This organism was the commonest form in human feces and second in abundance in cow-dung.

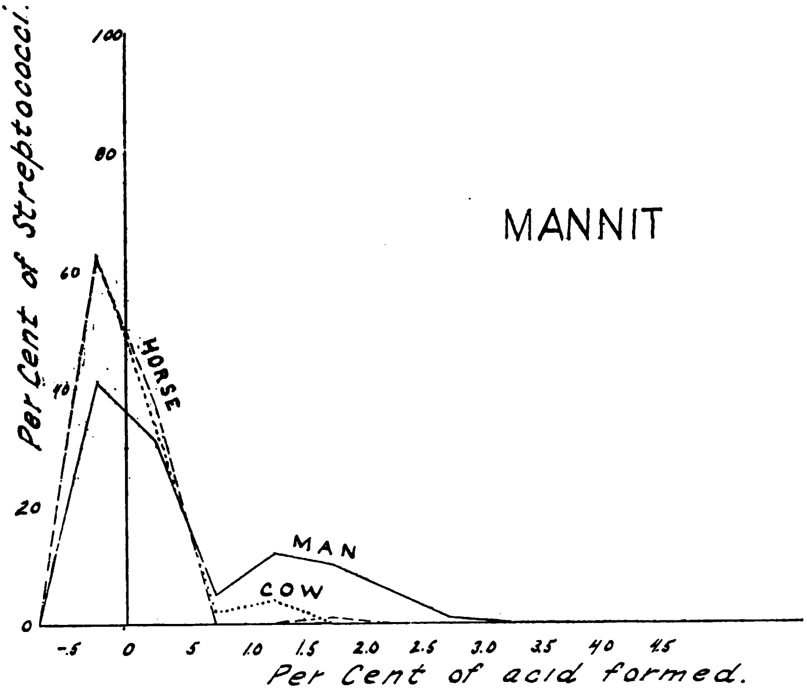

CHART 4.—Acid producing power of streptococci in mannit broth.

Finally 23 per cent of the human strains belonged to the type of Strept. fecalis, characterized by fermentation of dextrose, lactose, and mannit. This form was not found at all in the feces of the horse and but twice in that of the cow, these results corresponding closely with those obtained by Houston.

The intestinal flora of the cow appears to be more complex than either of the others. Strept. equinus and Strept. mitis are the commonest types but two other forms were also present in considerable numbers. Nine per cent of the strains belonged to the type of Strept. salivarius, characterized by the fermentation of dextrose, lactose, and raffinose. Twelve per cent of the cultures were of a new type, not apparently described hitherto, having the peculiar property of attack-

TABLE 5.
STREPTOCOCCI ISOLATED FROM HUMAN FECES.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	25	4.4	3.0	.1	.1	59	78	3.3	0	−.2	−.1
2	26	3.1	2.7	.4	1.7	60	78	2.9	0	+.2	−.1
3	26	3.9	3.0	.2	1.6	61	78	1.1	.2	+.2	−.2
4	26	3.6	2.8	0	.2	62	78	3.5	0	.1	0
5	27	3.4	3.0	.2	1.5	63	78	2.9	0	−.1	−.3
6	27	3.0	2.8	.2	.1	64	78	1.6	1.1	−.0	−.2
7	27	3.6	2.7	.3	.3	65	78	1.7	1.8	+.2	−.2
8	27	3.6	2.7	.3	.2	66	78	2.0	1.6	−.0	−.2
9	27	4.4	3.1	.1	.3	67	78	.1	0	−.2	−.1
10	27	3.8	2.5	.1	.9	68	78	3.2	0	−.0	−.2
11	27	3.0	3.1	.2	.4	69	78	4.4	2.7	+.2	−.1
12	27	4.1	2.9	.2	.3	70	78	.1	.1	−.0	−.2
13	27	3.8	3.0	.4	.2	71	78	0	.1	+.1	−.1
14	27	3.0	2.7	.1	.4	72	78	−.1	.1	+.1	−.1
15	27	3.3	2.8	0	1.7	73	78	2.6	0	0	1.9
16	28	3.9	3.2	0	.1	74	78	3.2	0	−.1	.8
17	28	4.3	2.8	.4	.1	75	78	3.2	0	.1	−.1
18	28	3.8	3.0	.1	1.3	76	78	3.0	0	.1	.3
19	49	4.3	2.4	.1	1.4	77	79	4.1	2.3	.3	2.6
20	49	4.0	2.8	.3	1.4	78	79	1.9	1.6	.2	1.6
21	49	4.1	2.9	.3	1.1	79	80	2.1	1.8	.2	1.6
22	49	3.9	2.7	.3	1.3	80	80	2.0	1.7	.4	1.7
23	49	4.0	3.1	0	1.2	81	80	2.0	1.7	.2	1.6
24	49	3.8	3.1	.3	1.2	82	80	2.1	1.6	.4	1.7
25	50	2.7	3.7	.9	0	83	80	2.2	.1	.3	1.5
26	50	2.3	2.8	1.4	.1	84	80	1.9	1.6	.2	1.6
27	50	2.6	3.5	1.0	0	85	80	1.9	1.7	.3	1.5
28	65	3.8	3.3	.2	.2	86	80	2.1	1.6	.3	1.7
29	65	.5	.1	.2	0	87	80	1.8	1.7	.4	1.5
30	65	4.6	3.1	.1	−.1	88	80	1.9	1.6	.2	1.5
31	65	4.2	.2	.1	.3	89	80	1.9	1.4	.4	1.8
32	65	4.5	2.3	3.2	.1	90	80	1.5	1.6	.2	1.5
33	65	.3	.2	.1	.1	91	81	2.3	2.7	.1	−.2
34	65	4.6	2.4	.2	.2	92	81	2.3	.1	.1	.1
35	65	3.6	0	.1	.3	93	81	1.7	3.0	.1	−.1
36	65	4.3	2.4	3.0	.1	94	81	−.1	2.9	0	−.1
37	65	2.7	0	.2	.1	95	81	2.5	2.8	2.6	−.3
38	65	.1	.1	.2	.2	96	81	.7	2.3	.1	−.1
39	65	2.9	0	.1	.3	97	81	2.1	1.4	−.1	−.2
40	65	4.0	.1	0		98	81	2.3	2.8	2.5	−.2
41	65	3.7	.1	.1		99	81	2.2	3.1	0	0
42	65	0	.2	0		100	81	1.6	3.1	0	.1
43	65	3.4	.1	0	0	101	88	3.4	.2	.1	.8
44	65	3.5	.1	0	−.1	102	88	3.2	1.9	0	1.1
45	65	3.5	0	−.1	0	103	88	4.5	2.1	.2	.8
46	65	3.9	0	0	0	104	88	4.8	2.4	0	−.1
47	65	3.4	0	0	0	105	88	3.6	.4	.2	.8
48	65	3.8	.1	0	0	106	88	2.9	2.2	.1	.3
49	65	3.4	.1	0	0	107	88	3.2	.5	.3	.6
50	65	.1	0	0	0	108	88	2.8	1.0	.1	.1
51	66	1.8	2.0	−.1	.1	109	89	.2	1.2	0	0
52	66	3.8	.3	.4	−.1	110	89	2.4	1.6	.2	−.1
53	66	4.9	3.3	.2	.1	111	89	2.7	−.1	.1	−.1
54	66	3.8	.3	.2	.1	112	89	0	−.2	.1	0
55	66	3.7	.1	.1	0	113	89	2.7	1.7	0	.4
56	66	5.4	3.2	.2	0	114	89	2.5	1.4	.1	.1
57	74	0	.1	−.0	−.1	115	89	2.7	.7	0	−.1
58	74	4.1	2.4	+.2	−.1	116	89	3.1	−.1	.1	−.1

ing lactose and raffinose but not dextrose. This is highly unusual since dextrose as the simplest sugar is almost always fermented before any other carbohydrate. We have hesitated however to give a name to this type while it is characterized by only 10 cultures.

TABLE 6.
STREPTOCOCCI ISOLATED FROM HORSE-DUNG.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	32	4.6	1.1	.8	1.9	51	46	.9	0	.1	0
2	35	1.4	1.3	.2	.3	52	46	0	.6	0	−.1
3	36	2.0	0	0	.1	53	46	1.9	.2	0	−.2
4	36	1.3	.2	0	0	54	46	1.9	−.2	0	0
5	36	1.7	.1	0	.1	55	47	2.2	2.7	.1	.1
6	36	2.1	0	.3	0	56	47	1.3	0	.1	0
7	36	.4	0	.2	0	57	47	1.9	0	0	0
8	36	2.1	0	.3	.1	58	47	2.1	−.1	0	−.1
9	36	1.9	0	0	0	59	47	1.6	−.1	0	0
10	36	.8	.6	.1	.2	60	47	1.6	.1	.2	0
11	37	2.6	0	2.8	.2	61	47	1.7	0	.1	−.1
12	37	1.1	.2	0	0	62	47	1.2	−.1	0	−.1
13	37	1.8	0	0	0	63	47	.2	−.1	−.1	0
14	37	1.0	0	.5	.3	64	47	2.4	−.1	0	−.1
15	37	2.3	0	.2	.1	65	47	2.3	.1	.2	0
16	37	2.3	0	.3	.1	66	47	2.5	0	0	1.2
17	37	1.0	0	.3	0	67	47	2.4	.1	0	0
18	37	.6	0	0	0	68	48	.2	−.4	.2	−.1
19	37	2.3	0	0	0	69	48	1.1	.3	−.1	0
20	37	2.5	0	0	.1	70	48	.1	0	.1	−.1
21	37	1.4	0	0	.1	71	48	1.5	−.2	0	−.3
22	37	1.5	0	0	0	72	48	2.2	−.3	0	−.2
23	37	1.6	0	0	.1	73	48	1.9	0	.1	−.1
24	37	1.8	1.6	0	0	74	48	2.0	0	−.1	−.2
25	38	.2	.2	0	0	75	48	1.5	.2	0	−.1
26	38	0	0	0	0	76	48	1.9	0	0	0
27	38	2.1	0	0	.3	77	48	1.8	−.1	0	0
28	38	1.4	0	.5	.1	78	48	−.1	0	0	−.2
29	38	1.5	0	.3	0	79	64	1.1	.1	0	0
30	38	1.9	0	.3	.1	80	64	1.3	0	0	.1
31	38	2.5	0	.5	0	81	82	1.0	.1	.1	.1
32	38	1.3	0	.2	.3	82	82	.8	0	0	−.1
33	38	2.0	.3	1.7	.1	83	82	1.1	0	.1	.1
34	38	2.3	0	0	0	84	82	.9	.1	.4	.1
35	38	.2	0	0	0	85	82	.8	.1	.1	0
36	38	1.9	0	0	0	86	82	.9	.1	.1	0
37	38	2.5	0	0	0	87	82	.8	0	.1	.1
38	38	2.1	0	.3	.1	88	82	1.4	.8	.2	.1
39	39	.3	.2	.3	.2	89	82	1.8	.6	.2	.1
40	39	.4	0	0	.2	90	82	1.2	−.1	.1	−.1
41	39	2.1	0	0	.1	91	82	.9	.1	0	.1
42	39	2.3	.1	0	0	92	82	1.1	0	.2	.1
43	39	1.8	.1	0	.2	93	82	.9	.1	.1	−.1
44	39	0	0	.3	.2	94	82	.8	.1	.1	0
45	39	0	0	.3	.1	95	82	.2	−.1	0	.1
46	39	0	0	.4	0	96	82	.8	.1	0	.1
47	39	1.3	0	.2	0	97	82	1.2	.1	0	.1
48	39	1.6	0	0	.1	98	82	1.1	.1	−.1	0
49	39	.2	0	0	0	99	87	.9	0	−.1	−.1
50	39	2.0	.3	2.0	0	100	87	1.0	0	0	0

CONCLUSIONS.

The general result of our investigations has been to confirm and extend the conclusions of the English bacteriologists. We have found, as Andrewes and Horder concluded from their analysis of

Houston's descriptions, that the chief types of streptococci in the normal human intestine are Strept. mitis, fermenting dextrose and lactose, and Strept. fecalis, fermenting dextrose, lactose, and mannit. In addition we would call attention to the presence of a peculiarly vigorous type of Strept. equinus fermenting dextrose only.

TABLE 7.
STREPTOCOCCI ISOLATED FROM COW-DUNG.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinnose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	41	2.1	2.0	0	0	44	69	3.0	.2	0	0
2	41	.6	0	0	0	45	69	0	.1	.1	.1
3	43	2.7	2.5	.1	0	46	69	.1	0	0	.1
4	44	3.4	3.4	1.2	.1	47	69	0	.2	0	0
5	44	2.9	2.2	0	0	48	69	2.0	2.0	0	0
6	44	2.1	2.1	0	.1	49	69	2.5	.2	.1	0
7	44	2.3	2.1	0	0	50	69	.2	.1	0	0
8	44	.2	3.0	2.6	0	51	69	2.5	.1	−.1	.1
9	53	2.3	2.4	2.0	0	52	69	0	2.0	0	0
10	53	0	3.1	2.0	0	53	69	2.5	1.7	−.1	0
11	53	4.1	2.9	0	.8	54	69	.1	.3	.1	0
12	54	2.2	2.6	1.7	0	55	69	.1	.1	0	0
13	54	2.1	2.6	2.0	.1	56	69	2.2	.1	−.1	0
14	54	−.1	−.2	−.1	−.1	57	70	2.5	−.1	.1	.1
15	54	−.1	2.9	−.1	0	58	71	2.3	0	.2	.1
16	54	0	3.1	2.0	−.1	59	71	2.5	0	0	−.1
17	54	−.2	3.0	2.3	1	60	71	2.4	−.1	.1	0
18	54	−.1	2.8	2.3	0	61	71	.1	−.1	.2	−.1
19	54	−.1	2.9	2.4	.1	62	71	2.5	−.1	.1	0
20	54	3.1	2.7	−.1	.1	63	71	2.8	0	.1	0
21	54	−.2	2.8	−.1	0	64	71	2.0	0	.1	−.1
22	54	3.3	3.0	.1	−.2	65	72	3.0	1.6	.2	.1
23	56	2.1	−.1	2.1	0	66	72	.3	−.1	0	−.1
24	56	3.7	2.6	−.1	1.4	67	72	3.3	−.1	0	.2
25	56	2.4	2.5	2.3	−.1	68	72	2.6	2.0	.1	−.1
26	56	0	2.9	2.3	.2	69	72	2.5	−.1	.1	.1
27	56	−.1	3.1	2.4	.1	70	72	2.4	.1	2.6	0
28	56	−.1	2.5	2.3	.1	71	72	2.2	−.2	.1	0
29	56	4.2	3.1	2.0	1.3	72	72	0	0	.0	0
30	56	0	2.9	2.3	0	73	72	2.2	0	.1	.2
31	56	3.5	2.9	2.5	−.1	74	72	1.9	−.1	.1	.1
32	59	3.5	2.9	0	.1	75	75	4.1	2.7	.2	0
33	61	3.5	2.9	0	0	76	77	3.7	.6	.1	−.1
34	61	4.2	3.1	0	.1	77	86	1.0	0	.1	.1
35	61	3.9	3.2	3.5	0	78	91	−.2	.1	.1	.1
36	61	3.9	3.5	0	0	79	91	.1	0	.2	.2
37	67	2.0	.2	0	0	80	92	2.3	1.6	1.4	1.3
38	67	1.1	.2	0	0	81	92	2.2	1.9	1.5	.9
39	68	.4	0	.1	0	82	92	.1	0	.1	.2
40	68	2.8	.2	−.1	0	83	96	.2	0	.2	0
41	68	2.6	.1	0	0	84	96	1.7	1.2	2.3	.1
42	68	0	2.3	−.1	0	85	98	2.8	2.6	3.0	0
43	69	2.0	0	0	.1	86	97	.3	0	0	−.1

We have found, as Andrewes and Horder did, that the characteristic streptococcus of the horse is the non-lactose-fermenting Strept. equinus; and this appears to be the only form typically present. Seventy-three per cent of all our equine strains belonged clearly to this type.

In the feces of the cow, on the other hand, streptococci which fail to ferment lactose are relatively less common, as Houston showed. Strept. equinus is present; but so are Strept. mitis and Strept. salivarius (fermenting dextrose, lactose, and raffinose); and we have found in small numbers a peculiar new type fermenting lactose and raffinose but not dextrose. Strept. fecalis, as in the horse, is absent.

From the standpoint of the water bacteriologist several conclusions may be drawn. In the first place, it appears that pollution with road washings may be distinguished from wastes of other sorts by a study of the streptococci present. Since most of the pollution in street washings comes from horse-dung, and since lactose-fermenting streptococci are comparatively rare in such deposits, a test for these organisms should have distinct value. Such a test might easily be made by inoculating tubes of lactose broth, incubating for several days, and then plating on lactose agar.

The distinction between human and bovine pollution is also promising. There are three points of difference which seem to deserve investigation. First the presence of streptococci forming over 3.5 per cent of acid in dextrose broth would seem in general to be characteristic of human stools. Second, raffinose-fermenting forms (Strept. salivarius) appear to be more abundant in bovine than in human feces. Third, and of most importance, mannit-fermenting streptococci (Strept. fecalis), which make up about one-quarter of the human streptococci, are very rare in the feces of the horse and cow. In this respect Houston's results and our own are in complete agreement; and the use of mannit broth as a differential test for streptococci of human origin would seem sufficiently promising to warrant further study.

REFERENCES.

ANDREWES, F. W., AND HORDER, T. J. 1906. "A Study of the Streptococci Pathogenic for Man," *Lancet*, 171, p. 708.

BETTENCOURT, A., AND BORGES, I. 1908*a*. "Recherches sur le B. coli des vertébrés inférieurs et des céréales," *Archivos do Real Instituto Bacteriologico Camera Pestana*, 2, Fasc. II, p. 221.

BETTENCOURT, A., AND BORGES, I. 1908*b*. "Peut-on distinguer le colibacille de l'homme de celui des animaux au moyen de la fixation du complément," *Archivos do Real Instituto Bacteriologico Camara Pestana*, 2, Fasc. II, p. 245.

FERREIRA, A., HORTA, A., AND PARADES, C. 1908. "Recherches sur le B. coli communis de l'intestin de l'homme," *Archivos do Real Instituto Bacteriologico Camara Pestana*, 2, Fasc. II, p. 153.

GORDON, M. H. 1904. "Report on a Bacterial Test for Estimating Pollution of Air," Supplement to the *Thirty-second Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1902–3, p. 421.

GORDON, M. H. 1905. "Report of Some Characters by which Various Streptococci and Staphylococci May Be Differentiated and Identified," Supplement to the *Thirty-third Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1903–4, p. 388.

HOUSTON, A. C. 1905. "The Bacteriological Examination of Milk," *Report to the London County Council*, July 11, 1905.

HOUSTON, A. C. 1906. "Report on the Bacteriological Examination of (1) Deep Well Waters; (2) Upland Waters; and (3) Cow-Dung," Supplement to the *Thirty-fourth Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1904–5, p. 326.

MACNEAL, W. J., LATZER, L. L., AND KERR, J. E. 1909. "The Fecal Bacteria of Healthy Men," *Jour. Infect. Dis.*, 6, p. 123.

WINLSOW, C.-E. A. AND A. R. 1908. *The Systematic Relationships of the Coccaceae.* New York.

AN INVESTIGATION OF THE EXTENT OF THE BACTERIAL POLLUTION OF THE ATMOSPHERE BY MOUTH SPRAY.*

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INTRODUCTION.

WITH the progress of exact knowledge sanitarians have been led to place less and less emphasis upon the part played by the atmosphere in the spread of zymotic disease. Bacteriological studies have shown that quietly expired air is germ free and epidemiological investigations indicate that little place is left for aerial transfer of disease in any form (Chapin, 1908). Even sewer air has been shown by recent work to be on the whole remarkably free from pollution with sewage bacteria.

On the other hand, Horrocks and Andrewes in England have demonstrated that a local pollution of sewer air does occur in the presence of mechanical splashing, taking the form of a fine spray of sewage, temporarily suspended in the air. Similarly, the work of Flügge and his pupils has shown that in sneezing, coughing, and loud speaking a spray is thrown out which contaminates the air for a considerable distance with bacteria from the mouth. It has been generally assumed that this mouth spray may be an important factor in the spread of tuberculosis, and other diseases affecting the respiratory tract.

The real importance of the mouth spray, as of any other vehicle of disease, can be properly determined only by quantitative investigations. The day of qualitative sanitation is fast passing. Not, "Is such a thing dangerous?" but, "How dangerous is it?" is the question we ought to ask. Applying this criterion to the bacterial content of sewer gas one of the writers has been led to the conclusion that on the whole the danger of infection from that medium is very slight (Winslow, 1909). In the present investigation the attempt has been made to apply similar quantitative standards to the mouth spray,

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and to determine whether the extent of air pollution with mouth bacteria under normal conditions is sufficient to be measured bacteriologically and to be estimated as a practical factor in the spread of zymotic disease.

PREVIOUS INVESTIGATIONS ON THE DISCHARGE OF BACTERIA IN MOUTH SPRAY.

It is particularly to Flügge and his pupils that we owe the most careful studies of the possibilities of aerial transmission of disease germs, either in the form of dust or in the form of fine spray (Flügge, 1897*a* and 1897*b*). He was the first to lay special stress upon the danger from the spray produced in coughing in the case of tuberculosis (Flügge, 1899), and to point out how much more important this danger is than the possibility that the disease may spread through the blowing about of dried sputum which before this time had been accepted on the basis of Cornet's classic work (Cornet, 1889) as the principal mode of disseminating the disease.

TABLE 1.

DISTRIBUTION OF BACTERIA BY MODERATELY LOUD SPEAKING.

Laschtschenko (1899).

Room, 90 cu.m. Speaking for 1 hour.

Distance of plate from speaker. Meters	0.5	0.75	1.0	1.25	1.5	1.75
Total plates exposed	1	3	1	2	3	2
Negative plates	0	0	0	0	0	0
Mean number B. prodigiosus per plate	450	32	10	6	4	8

TABLE 2.

DISTRIBUTION OF BACTERIA BY LOUD SPEAKING (ONE HOUR).

Laschtschenko (1899).

	Mean Number B. prodigiosus per Plate					
Distance. Meters	1	2	3	4	5	6
Small room (50 cu.m.)	1	3	2	0	1	1
Large room (90 cu.m.)	5	10	..	3	..	..

The first important experiments upon mouth spray were carried out by Laschtschenko, and upon them Flügge's earlier papers were largely based, altho the full results were not published until two years later (Laschtschenko, 1899). The general method employed in these experiments consisted in inoculating the mouth with a heavy suspension of B. prodigiosus in normal salt solution and then causing the subject to cough, sneeze, or speak loudly for a specified length of time. Agar plates were exposed at various distances to receive any bacteria which might settle upon them. Some of the experiments were made in a glass chamber of 3.2 cubic meters capacity provided with an opening for the mouth of the investigator; others were carried out in rooms of 50 and 90 cubic meters capacity.

Quiet speaking, in the glass chamber, showed a few colonies; in the larger room, none. The results for moderately loud speaking and for loud speaking we have tabulated for convenient reference in Tables 1 and 2.

A general summary of all the loud and moderately loud speaking experiments grouped together is given in Table 3.

Coughing and sneezing of course gave higher results which need not be considered in detail. Sneezing distributed the infection for nine meters.

The most significant of Laschtschenko's experiments were carried out with tuberculous patients. The coughing of such a patient while sitting for an hour in the glass chamber, to which reference has been made, distributed virulent tubercle bacilli, as evidenced by animal tests made with normal salt solution exposed in the chamber during the test. The actual extent of the air pollution was however slight, as shown by drawing off the air of the chamber, filtering, and injecting into guinea-pigs. When less than 2 cu.m. of air per hour were examined, no positive results were obtained; but out of five tests covering a period of five hours each, and involving the filtering of 10 cu.m. of air in each case, two tests showed virulent tubercle bacilli.

Hübener (1898) carried out a series of similar experiments with a view to the danger of infecting patients upon the operating table from the mouth. His method consisted in exposing four agar plates about 50 cm. in front of and below the face of a subject who had infected his mouth with B. prodigiosus. In 11 experiments in which the subject counted aloud for 10 minutes the number of colonies on the four plates varied from 101 to 1,507 and averaged 458; two tests with three or four coughs gave 223 and 265 colonies and in two tests a single sneeze gave an uncountable number.

TABLE 3.

GENERAL SUMMARY OF LASCHTSCHENKO'S EXPERIMENTS.

	90 cu.m. Room	50 cu.m. Room
Total plates	24	12
Mean number B. prodigiosus per plate	25	1.5
Per cent of negative plates	8	33

Along similar lines, Hamilton (1905) has shown that streptococci are expelled from the mouth in coughing, speaking, and even forcible breathing, and has emphasized the danger of surgical infection from this source.

V. Weismayr (1898) obtained somewhat different results which indicated a more restricted distribution of mouth spray than that reported by other observers. He found B. prodigiosus on plates directly in front of a coughing subject in quiet air up to a distance of 4 meters, but not beyond and not out of the zone directly in front of the mouth. When the air of the room was agitated, however, he found small numbers of bacilli 1–2 meters behind and at the side of the subject. In speaking experiments infection could not be traced at distances over 1 meter. Slides exposed before the mouths of coughing consumptives showed tubercle bacilli only rarely.

The most exhaustive of all the experimental studies of the spread of B. prodigiosus in mouth spray was perhaps that carried out by Koeniger (1900). He followed in the main the methods of Laschtschenko, making in all 18 speaking experiments in two rooms, one of 97, the other of 440 cu.m. capacity. His main results have been summarized in Table 4.

Koeniger observed also the amount of infected spray discharged by enunciating various letters and showed that consonants like *p* and *t* caused the greatest pollution. The amount of spray of course increased with loudness and sharpness of speech but, as indicated in the table below, whispering, with its clear enunciation, gave higher results than gentle speech in an ordinary tone.

TABLE 4.

DISTRIBUTION OF BACTERIA IN MOUTH SPRAY.

(Koeniger, 1900.)

Speaking, generally for 15 minutes.

	TONE OF VOICE				
	Sharp	Loud	Moderately Loud	Soft	Whisper
Total plates	30	101	143	23	24
Mean number B. prodigiosus per plate	14.5	7.8	2.1	1.4	5.3
Total negative plates	0	9	91	16	10
Per cent negative plates	0	8.9	63.6	69.6	41.7

Koeniger found B. prodigiosus on his plates in all parts of the room, at extreme distances of 12.4 meters in front of the speaker and at one side of and behind him. In this respect his results differ from those of v. Weismayr. On the other hand, he made important observations on the length of time for which the bacilli would remain in the air which contradict Flügge's conclusion, based on experiments with atomizer spray, that bacteria from the mouth might remain suspended in the air for 4 or 5 hrs. Koeniger's general results are brought together in the table below. B. prodigiosus was never found in quiet air an hour after the speaking had ceased, tho when the air of the room was agitated by moving about and opening and shutting doors, positive results were obtained after an hour and a half.

TABLE 5.

SETTLING OUT OF MOUTH SPRAY IN QUIET AIR.

(Koeniger, 1900.)

Interval between Speaking and Exposure of Plates. Minutes	Percentage of Colonies Found, Taking Number on Plates Exposed during Speaking as 100
0	95
10	38
20	9.8
30	5.5
45	2.7
60	0.7
90	0.0
105	9.6*
120	0.0
150	0.0

* Air agitated.

Experiments with B. mycoides made in similar fashion showed a much more limited distribution of mouth spray than was observed in the case of B. prodigiosus. Out of 105 plates exposed during 15 minutes' speaking only 23 showed colonies of the specific germ. The average number of colonies per plate was 7 and the maximum distance 3 meters. All plates exposed 10 minutes after speaking were sterile.

Gordon in England was the next to take up this work and his investigations confirmed in all respects the work of Laschtschenko and Koeniger (Gordon, 1904). Repeating the B. prodigiosus experiments he traced aerial infection for 12.2 meters in front of the subject and for 3.7 meters behind him. We have summarized these particular experiments in Table 6 below. Gordon's most important contribution to the whole subject lay in the suggestion that the mouth streptococcus might be used as a normal index of mouth pollution without the use of artificial B. prodigiosus inoculations; but this aspect of his work will be considered farther on.

Mention may perhaps be made here of experiments by Flügge (1897), Buchner, Megele, and Rapp (1899), and Hutchison (1901), which have shown, as might be expected, that bacteria artificially sprayed into the air can be transported by air currents of low velocity for considerable distances. Buchner, Megele, and Rapp found a limiting velocity of 1 mm. per second for B. prodigiosus and 1.3–1.8 mm. per second for yeast cells 3–10 microns in diameter. Little can be learned from such experiments as to the behavior of the mouth spray itself which may be in a much grosser state of division.

So far reference has been made for the most part only to experiments in which B. prodigiosus was used as an indicator of the distribution of bacteria in the mouth spray. Another important series of investigations has dealt more directly with the practical question of the spread of tuberculosis by observations of the behavior of the tubercle bacillus itself. Laschtschenko's work along this line has already been discussed. At about the same time Englemann (1898) and Heymann (1899) showed that tubercle bacilli could be detected on plates of various sorts exposed within 0.5–1 meter of coughing consumptives; and Heymann succeeded in infecting 6 out of 25 guinea-pigs exposed 20–45 cm. in front of coughing consumptives, with heads fixed toward the patients.

TABLE 6.

DISTRIBUTION OF BACTERIA IN MOUTH SPRAY.
(Gordon, 1904.)
Generally, loud speaking for 1 hour.

Total plates exposed	30
Mean number B. prodigiosus per plate	0.7*
Total negative plates	14
Per cent negative plates	47

* Number on four positive plates not stated.

Fränkel (1899) found that out of 219 masks worn by tuberculous patients 52 showed macroscopic evidence of contamination with sputum; in 26 of the latter tubercle bacilli could be demonstrated by staining. Fourteen patients wore the masks in these experiments. Two yielded positive results almost always, one frequently, 3 once each, and 8 never showed tubercle bacilli on the masks.

In a later investigation, Heymann (1901) shut up a coughing consumptive patient in a small chamber for an hour or two. At the close of this period the patient left the chamber and broth plates were exposed, after the chamber had remained quiet, for varying periods, 15, 30, or 90 minutes. Of 24 guinea-pigs inoculated with broth thus exposed, two which had received broth exposed 30 minutes after the end of the coughing developed tuberculosis. In a second series of tests the air in the chamber was drawn off and washed, and the sediment in the washings centrifuged and injected. Of 14 guinea-pigs injected with the sediment from 7 cu.m. of air drawn off while the coughing was in progress only two became infected; of 22 guinea-pigs injected with the sediment from 11 cu.m. of air drawn off at periods of 15–60 minutes after the coughing stopped, all remained sound. Many more recent observers have shown that tubercle bacilli may be found on plates exposed before coughing consumptives. The most exhaustive of these investigations is perhaps that of Ziesché (1907). He arranged a vertical plate having an area of 324 square centimenters at a distance of 40–80 cm. from the mouth of phthisical patients and counted under the microscope the number of tubercle bacilli discharged in half an hour. Of the patients examined only once 12.5 per cent gave positive results; of those frequently examined, 78.9 per cent. Altogether 29 out of 62 tests were positive. Of the 29 positive plates, 3 showed less than 10 bacilli, 15 from 10 to 100, 7 from 100 to 500, 2 from 500 to 1,000, one 1,445, and one 20,174 bacilli.

Similar observations have been made in the case of leprosy. Schäffer (1898) found leprosy bacilli on glass plates exposed before the mouth of a leper after 10 minutes' reading. Plates near the mouth showed many thousands of bacilli and infection could be traced to a distance of 1.5 meters. These experiments were repeated and confirmed by Hübener (1898) in a paper to which reference has been made above.

It is sufficiently clear from a consideration of all these investigations that bacteria may indeed be discharged from the mouth in such a way as to spread disease. On the other hand it seems equally clear from the tuberculosis experiments that the practical danger is confined to a local discharge of spray rather close to the mouth of the patient. Rightly interpreted there is no basis in any of this work for the conclusion that disease is spread broadcast through the atmosphere. Professor Flügge's own treatment of the matter is judicial and conservative. He lays stress only on coughing, not on speaking, as a possible danger. He points out that in experiments carried out by his pupils tubercle bacilli were abundant only within 0.5 meter of the coughing patient and that beyond 1.5 meters their number was so small as to make the chance of infection practically nil. He notes that only certain phthisical patients discharge infected spray when they cough and that others do so only at certain periods of the disease, and only at certain times of day. In one of his first papers (Flügge, 1897*b*), he says: "Altogether it appears that under natural conditions the infection resulting from sputum spray is not so significant as one might think at first sight." In a later paper (Flügge, 1901) the following rational rule is laid down: "During strong paroxysms of coughing, the consumptive should keep at arm's length from his companions and should hold a handkerchief before his mouth. In workrooms, offices, and such places the space between the heads of the workers should be at least 1 meter."

No exception can be taken to such conclusions as these. Unforunately, however, others have not been so conservative. The B. prodigiosus experiments particularly have lent themselves to misleading interpretations. It is common to see statements to the effect that bacteria are discharged from the mouth in coughing, sneezing, and even loud speaking to distances of 12 meters and in all directions behind as well as in front of the subject; and from such unqualified statements the inference is implicitly drawn that a general infection of the atmosphere takes place over a wide radius and that there is real danger of infection from breathing the air in the neighborhood of a consumptive. Fränkel (1899) early took up an extreme position, speaking of spread through the air as the "most frequent cause of tuberculosis," and recommended the wearing of masks by tuberculosis patients discharging bacilli freely. This was ten years ago, it is true; but Tendeloo (1908) at the last Tuberculosis Congress said: "It has been proved by numerous experiments (Cornet, Flügge, etc.), that bacteria floating in the air, either in dry dust particles, or suspended in minute fluid particles, may be inhaled into the bronchi, bronchioli, and air-vesicles, where they fall down just like inhaled dust particles;" Pannwitz (1908) said: "If they contain a coughing tuberculous patient, inclosed spaces, such as dwelling-houses, workshops, counting-rooms, public halls, railway coaches, and steamer cabins, are speedily converted into tuberculosis-inhalatoriums in which healthy persons may infect themselves;" and Bernheim (1908) recommended the wholesale disinfection of air on the ground that "there is an intimate relation between tuberculosis and the microbes of the air. The more highly the atmosphere is charged with bacteria the greater is the number of consumptives living in that unhealthy environment."

As a matter of fact it can be shown that even the B. prodigiosus experiments do not indicate any general atmospheric infection in the proper meaning of the term; and studies of the discharge of tubercle bacilli and of normal mouth bacteria show that the spread of these organisms is insignificant in comparison with the discharge of B. prodigiosus in culture media with which the mouth has been artificially infected.

REPETITION OF EUROPEAN EXPERIMENTS ON AIR POLLUTION BY MOUTH SPRAY USING B. PRODIGIOSUS AS A TEST ORGANISM.

The first object of our own experiments was to extend and place on a quantitative basis the work of Flügge's pupils on air pollution by mouth spray. It was necessary therefore to follow their procedure rather closely, using B. prodigiosus as a test organism and detecting it by the simple exposure of plates, in order to be sure that the conditions of their work were fairly duplicated. At the same time we examined measured volumes of air and determined the actual number of specific germs present by methods discussed in the succeeding section.

Three methods were employed in our experiments for inoculating the mouth with B. prodigiosus. The first was to pour water on an agar slant culture, shake so as to get a suspension, rinse out the mouth with the suspension for a minute, and reject the surplus water. The second was to transfer the organisms directly from the culture to the mouth by means of a platinum loop. The third was to transfer the bacteria on a loop to a small quantity of water (1 or 2 c.c.) which could be entirely retained in the mouth. The last method proved most satisfactory. Analyses of the saliva at the close of the experiments generally showed that B. prodigiosus was present in 10^{-6} c.c.

In the first 10 experiments the subject read from a book in a loud tone and at a fairly rapid rate. Beginning with Experiment 11 and continuing through the series the subject repeated from memory verses in English and German, in a loud tone and with exaggerated enunciation. The discarding of the book appeared to facilitate the spread of bacteria.

The tests were carried out in three laboratories of the Institute of Technology. Two of them are about 6×8 meters in area and 3.7 meters high; the third is 11×8 meters and 3.7 high. In the qualitative work ordinary plates were exposed in different parts of the rooms at varying heights and at varying distances from the speaker. The speaking usually lasted for 15 minutes and the plates were exposed during this time and for a varying period, generally three-quarters of an hour afterward. The speaking was done by four different subjects during the course of the experiments.

The general results obtained by the simple exposure of Petri plates are indicated in Table 7. The speaking was continued for 15 minutes in each case except in Experiments 14 (7 minutes), 15 (13 minutes), and 21 and 23 (10 minutes).

It will be noticed that the substitution of speaking for reading,

TABLE 7.

B. PRODIGIOSUS ON PLATES EXPOSED IN ROOM POLLUTED BY MOUTH SPRAY.

EXPERIMENT	PERIOD OF EXPOSURE MINUTES	NUMBER OF PLATES	TOTAL COLONIES	MEAN PER PLATE	NEGATIVE PLATES	
					Total Number	Percentage
7	15	11	1	.09	10	91
8	15	12	2	.16	11	92
9	15	18	2	.11	16	89
10	15	21	4	.19	17	81
11	75	25	22	.88	14	56
12	15–75	42	3	.07	39	93
13	75	24	22	.92	10	42
14	..	25	9	.36	18	72
15	73	25	20	.80	16	64
16	135	13	34	2.6	3	23
17	..	11	68	6.2	3	27
18	45	10	134	13.4	0	0
19	60	12	88	7.3	0	0
20	60	14	75	5.4	0	0
21	60	14	142	10.1	0	0
22	75	12	56	4.7	4	33
23	25–70	36	98	2.7	8	22
Totals and averages		325	780	2.4	169	52

at and after Experiment 11, caused an increase in positive results and that as the later experiments progressed the number of bacteria on the plates continued to increase, perhaps as a result of more thorough inoculation of the mouth or more vigorous enunciation. Control plates, 22 in number, exposed just before Experiments 19 and 20, were all negative, showing that no serious permanent pollution of the room air had taken place.

In general these results agree closely with those obtained by the German and English observers cited earlier in the paper. The more important data are presented for comparison in Table 8.

TABLE 8.

COMPARATIVE RESULTS OF VARIOUS OBSERVERS ON EXPOSURE OF PLATES IN ROOMS POLLUTED BY MOUTH SPRAY.

Observer	Total Plates Exposed	B. prodigiosus. Mean Colonies per Plate	Percentage of Negative Plates
Laschtschenko	36	17.2	17
Koeniger	321	5.2	39
Gordon	30	0.7	47
Winslow and Robinson	325	2.4	52

Laschtschenko's figures are a little high; but with that exception the results are entirely concordant. It is clear that loud speaking discharges bacteria from the mouth in the form of spray; and that by inoculating the mouth of the speaker with B. prodigiosus and exposing plates in the room the specific germ may be detected in considerable numbers.

Suggestive data in regard to the distribution of the mouth spray in space may be obtained by analyzing the results of our experiments according to the distance of the plates from the position of the speaker. The results for each point at which ten or more plates were exposed in different experiments are brought together in Table 9. The heaviest pollution appears to be between 2 meters and 4.5 meters from the speaker. The spray from the mouth probably shoots over areas which are too near; and the particles which are carried beyond 4.5 meters are fewer in number.

TABLE 9.

B. PRODIGIOSUS ON PLATES EXPOSED AT VARIOUS DISTANCES FROM THE SPEAKER.

Distance Meters	Total Plates	Total Colonies	Colonies per Plate
1.0	13	2	.15
1.5	28	62	2.22
2.0	48	199	3.96
2.5	22	126	5.73
3.5	50	208	4.16
4.5	13	40	3.08
5.5	33	61	1.85
7.0	14	32	2.28
7.5	31	42	1.35

Some idea of the general extent of superficial pollution due to mouth spray may be gained from the following considerations. In the room used for all the plate experiments except 7, 9, and 12, 254 plates were exposed and 774 colonies of B. prodigiosus developed, an average of 3.5 colonies per plate. The total area of the room was 480,000 sq.c. and the mean area of a plate 54.5 sq.c. Assuming that all the organisms above a plate settled upon it, the mean number of B. prodigiosus in the whole room in each experiment would be $\frac{480{,}000 \times 3.5}{54.5}$ or 30,830, and the number discharged on a square meter of surface (by 15 minutes' speaking) would be 646.

QUANTITATIVE METHODS OF ENUMERATING BACTERIA IN THE AIR.

The various processes suggested for enumerating bacteria in the air may be classified broadly under two main heads, filtration methods and sedimentation methods. In one case a measured volume of air is filtered through a powdered solid medium (asbestos, salt, sugar, sodium sulphate, cotton, sand, glass wool) or is bubbled through a liquid. The solid filtering medium is washed in sterile water and aliquot portions of the water are plated; or portions of the liquid through which the air has been bubbled are plated directly. In all these procedures there is some danger that bacteria may be lost if the medium is not of sufficient fineness, or if the passage of the air is too rapid or if the connections of the apparatus are not all tight. The proper collection of samples with a fine filter on the other hand is time consuming.

The second group of methods involves the exposure of surfaces of nutrient media upon which the bacteria from a known volume of air may settle out and on incubation develop colonies. In its most primitive form ordinary Petri plates are left open in a room for known periods of time. The objection to this is twofold. In the first place the bacteria which fall upon the plates are not related to any determinable quantity of air. In the second place their number will vary greatly with the effect of chance air currents. Hesse long ago founded a more exact method upon this general principle by drawing air slowly through a long cylindrical tube lined with nutrient medium. Recently an improvement on this procedure has been suggested by one of us (Winslow, 1908) involving the use of two liter-and-a-half bottles, having gelatin on the bottom. The bottles are joined by tubing in tandem and a liter of air is drawn in by another water-suction bottle and the bacteria allowed to settle out. The chief objection to this procedure lies in the cumbrousness of the apparatus which requires the carrying about of two large bottles for every sample to be examined. For investigations in the laboratory, however, this procedure has many advantages.

In the present study three methods have been used. Most of the determinations were made by the culture bottle method; and in connection with this procedure two methods of collecting samples have been tried, one the usual method of drawing in air by connecting the second culture bottle with a water-aspirator, the other a vacuum method like that used in collecting air samples for carbon dioxide. In this case the culture bottle is first prepared by covering the bottom with gelatin, plugging with cotton, and sterilizing. At the same time a number of vaselined one-hole rubber stoppers plugged with three-inch lengths of capillary tubing are separately sterilized in a pipette case. If the bottles were sterilized with the rubber stoppers in them the breakage would be heavy; but after sterilization the stoppers may be substituted for the cotton plugs. Each bottle is then attached by the capillary tube to a suction pump and the air is exhausted for about 10 minutes or until a 90–95 per cent vacuum has been obtained. The capillary tube is now sealed in a flame and the sample of air may be taken at any time by removing the stopper. The danger of leakage from imperfectly fitting stoppers is considerable in this method and many bottles must be discarded but there is a great saving of time in sampling.

Another method used in a few determinations is a simple modification of the plate method designed to secure quantitative results with protection from air currents. An ordinary plate is opened and a covered cylinder a little larger than the plate and about 20 cm. high is placed over it. The apparatus is allowed to stand for half an hour so that the bacteria may settle. Finally in some of the later experiments with mouth bacteria the sand filter method was used, air being drawn by means of a suction bottle through a tandem filter, each member holding a 1.5 cm. layer of sand passing a sieve with 100 meshes to the inch.

QUANTITATIVE STUDY OF AIR POLLUTION BY MOUTH SPRAY USING B. PRODIGIOSUS AS A TEST ORGANSIM.

There are two objections to the method of exposing Petri plates as a measure of true air pollution. In the first place the procedure is necessarily an inaccurate one since the number of bacteria settling is conditioned not only by the number present in the air but also by the amount of motion in the atmosphere. In a strong current of air the plate method must yield results which are relatively too low. On the other hand in quiet air with heavy particles falling through it the results of the plate method must be too high. In the special case with which we are concerned the loud speaking, coughing, or sneezing produces a fine rain which falls more or less rapidly during the period of actual speaking and for a short time afterward. The rate of fall for small falling bodies may be approximately determined from Stoke's law which for spheres of density 1, calling the density of air .00018 and calling *g* 980, reduces to the form

$$v = 1{,}200{,}000r^2$$

where v is in centimeters per second and r is the radius of the falling particle in centimeters. An ordinary bacterium with a radius of about 0.0001 cm. should therefore fall through quiet air at a rate a little under 0.012 cm. per second, or about 17 inches per hour. If single isolated bacteria were discharged in the mouth spray their fall would be slow and would go on for several hours. As a matter of fact however such is not the case, as is made clear by Koeniger's experiments which have been cited above. He found that 60 per cent of the bacteria in the mouth spray disappeared from the air in 10 minutes, while after 20 minutes less than 10 per cent of the original number remained.

In two of our experiments similar data were obtained by opening all the plates before the speaking but removing some of them after various intervals. The results as shown below indicate no increase in bacteria after the actual period of speaking itself.

TABLE 10.

DURATION OF AIR POLLUTION BY MOUTH SPRAY.

Total B. prodigiosus on plates.

Period of exposure after speaking. Minutes	0	15	30	60
Experiment 12	1	2	..	0
Experiment 23	..	36	34	28

Clearly the mouth spray is a fairly coarse rain which settles out for the most part in 15 or 20 minutes. With such a rain as this the exposure of plates must give an exaggerated idea of the bacterial content of the air. Everything from the air above falls on the plates; but a liter of air should be credited only with the bacteria which it contains at a given moment. Many, even of these, cannot fairly be considered as constituting real aerial pollution if they are in large droplets, for such droplets would be too heavy to be drawn into the mouth with the inspired air.

In order to distinguish between coarse rain falling through the air and finer mist suspended in it, for a period of some minutes at least, we made quantitative determinations by the culture bottle method in Experiments 2, 5, and 6 and in Experiments 15–23, and by the covered plate method in Experiments 7, 8, 22, and 23. In the first three experiments the samples were collected during the speaking by another person. In the last nine the samples were collected just after the speaking by another person, or by the speaker himself with carefully washed hands. The results of the culture bottle tests are shown in Table 11 below.

TABLE 11.

Quantitative Pollution of Atmosphere by Mouth Spray.

Experiment	Duration of Speaking. Minutes	Mean Colonies per Plate Exposed at Same Time	Number of Liter Samples	Number of Samples Showing B. prodigiosus
2	50	..	5	0
5	15	..	3	0
6	35	..	9	0
15	13	0.8	8	0
16	15	2.6	5	0
17	15	6.2	3	0
18	15	13.4	11	1
19	15	7.3	8	0
20	15	5.4	8	0
21	10	10.1	10	2
22	15	4.7	16	0
23	10	2.4	19	0
Total			105	3

Examinations were made by the covered plate method described above in Experiments 7, 8, 22, and 23. Immediately after the close of the speaking the plates were opened and covered with the cylinders which were allowed to stand 30 minutes for the bacteria present to settle. This period is theoretically too short but as a matter of fact the results as shown in Table 12 below were higher than those obtained by the culture bottle method.

TABLE 12.

Air Pollution by Mouth Spray Measured by Covered Plate Method.

Experiment	Duration of Reading. Minutes	Mean Colonies per Plate Exposed at Same Time	Number of Samples	Mean Volume of Air Inclosed	B. prodigiosus Found
7	15	0.09	10	840	0
8	15	0.16	11	840	0
22	15	4.7	7	1,370	2
23	10	2.4	7	1,370	2
Totals and averages			35	1,050	4

Altogether taking both quantitative methods into account 140 liters of air were examined and B. prodigiosus was found seven times. The four positive tests with the covered plate were obtained at points about 2 meters in front of the speaker. Two of the positive culture bottles were at the extreme end of the room, nearly 7 meters from the speaker; the other was at a distance of more than 5 meters. These last results were obtained in the two experiments out of the whole series (see Table 11) which gave the largest number of colonies on the plates.

GORDON'S SPECIFIC TEST FOR AIR POLLUTION.

There is one weak point in all experiments involving an artificial inoculation of the mouth. We have no certainty that the bacterial emulsion introduced in this way behaves as the normal or pathological fluids of the mouth would do. It seems highly probable that a liquid with which the mouth has but just been rinsed would be ejected more freely than the sputum itself. In fact Heymann (1899) and Ziesché (1907) were able to show that in the mouth spray of a consumptive there are several distinct types of droplets which can be distinguished under the microscope and that it is only in droplets derived directly from the bronchi with but little admixture of mouth saliva that the tubercle bacilli are abundantly present. Some more direct test of normal mouth pollution than that furnished by the B. prodigiosus experiments is therefore greatly to be desired.

The real desideratum in the bacterial examination of air is a test which shall quantitatively detect the presence of some normal mouth bacterium which might serve as an index of mouth pollution as the colon bacillus serves in water analysis as an index of intestinal pollution. Such an index has been suggested by Gordon (1904), but its value has not been confirmed by subsequent investigations so far as we are aware. Gordon pointed out that one of the commonest organisms in the saliva is a streptococcus which he called Strept. brevis and which has since been more fully described by Andrewes and Horder (1906) as Strept. salivarius. It is a short chained form which renders broth uniformly turbid, clots milk, reduces neutral red, and ferments saccharose, lactose, and raffinose. Gordon found streptococci capable of fermenting lactose present in from one-millionth to one-hundred-millionth of a cubic centimenter of saliva. Similar streptococci which fail to ferment lactose or ferment neutral red were found to be present in ordinary street air but lactose-fermenting streptococci were absent. Gordon examined 10 samples of 50 liters of street air for streptococci by bubbling it through salt solution which was later mixt with nutrient broth. He found a lactose-fermenting streptococcus only once.

On the other hand, he found that the mouth streptococci could be easily detected in rooms polluted by mouth spray. His method consisted in exposing plates 3.5–5 inches in diameter containing neutral red broth, which was later incubated under anaerobic conditions. In a small room, 4.7 by 4.0 meters in area, 2 out of 6 plates showed mouth streptococci after 15 minutes' loud speaking, 4 out of 6 showed them after half an hour's speaking, and in 5 separate experiments after one hour of speaking 22 out of 30 plates gave positive results. In a larger room, 14.9 by 11.6 meters, 11 out of 34 plates and 28 out of 40 plates were positive after one hour's loud speaking. Quiet speaking and reading yielded negative results. These results coincide closely with those of the German experiments. Like them they measure the superficial discharge of spray but give no clear idea of the quantitative distribution of bacteria in the air above.

QUANTITATIVE STUDY OF AIR POLLUTION BY MOUTH SPRAY USING THE PRESENCE OF MOUTH STREPTOCOCCI AS AN INDEX.

Our final experiments were devoted to the examination of air polluted by mouth spray with a view of determining to what extent the mouth streptococci can be detected in the air itself by ordinary quantatitive methods.

In the first test of this sort the air was examined by the culture bottle method, lactose broth being used in the bottles instead of gelatin. The bottles were placed on a table directly in front of the speaker and from 0.6 to 2.4 meters away. In the first half of the work the speaker's mouth was 0.7 meters above the table and in the second half 1.2 meters above. Five liters of air were first examined for controls. Then the subject orated for 20 minutes, 4 liters of air being examined after each five-minute period. None of the 16 samples showed lactose-fermenting streptococci.

In the second and third experiments the air was examined by the sand filter method. In the second experiment, five different subjects orated loudly for a period of 10 minutes apiece (one taking part twice, so that six samples of air were examined). While the speaking by each subject was going on a sample of 4.5 liters of air was collected by attaching a water aspirator to a tandem sand filter placed between 0.9 and 1.5 meters away from the speaker and directly in front of him. Each filter in the pair held a layer 1.5 cm. deep of sand which had passed a sieve having 100 meshes to the inch (finer than 0.25 mm.). After collecting the sample the sand was poured into bent dextrose broth tubes and incubated for four days at 37°. Litmus lactose agar plates were made from the broth tubes which showed growth. No lactose-fermenting streptococci were found in any case so that the 27 liters of air examined in this experiment were again all negative.

The third experiment was similar to the second, except that conditions were more severe. Seven tests were made, with two different subjects. The speaking was in English and German and was loud with very vigorous enunciation. In two tests the speaking was interspersed with considerable coughing. Samples of 4.5 liters each were collected during each period of speaking (10 minutes) from a point 35 cm. away from the speaker's mouth and 15 cm. below it. The sand was incubated in dextrose broth for a week, and litmus-lactose plates were inoculated at intervals from the broth tubes. No lactose-fermenting streptococci were found in this examination of 31 liters of air.

Altogether 74 liters of air exposed to pollution by mouth spray were examined by these quantitative methods for mouth streptococci with uniformly negative results. From these experiments it appears, as might be expected, that the pollution of the atmosphere by normal mouth streptococci is considerably less than the contamination with B. prodigiosus after inoculating the mouth with that organism.

Gordon's experiments, made with plates exposed during an hour's reading, of course constituted a very severe test since the plates received all the heavy spray which fell through the air during that period. We made a final experiment along similar lines to his, using litmus lactose agar instead of broth. Eight plates were exposed 45 cm. below and 45 cm. in front of the mouth of the speaker and eight others 15 cm. below and 15 cm. in front. In all these cases the speaking was loud, and vociferous, in English and German, and the period of exposure was five minutes. Finally four plates were exposed 15 cm. in front of and 15 cm. below the mouth of the speaker who orated and coughed for three minutes.

The plates were incubated for four days and subcultures were made from all suspicious colonies. All showed large colony counts (87 to 1,200). Of the first eight plates exposed to spray from speaking 45 cm. away, one only showed a single colony of the acid-forming streptococci. Of the eight plates exposed to spray from speaking 15 cm. in front of and 15 cm. below the mouth, three gave positive results. Two of the plates showed each a single colony, the third was wholly reddened so that the number of acid colonies could not be exactly determined. The streptococcus colonies were not in isolated pure cultures but in mixt colonies each of which was obviously derived from a droplet of saliva containing many forms. Of the 16 plates examined in these two series three were overgrown with an alkalin spreader which might have obscured any streptococci present.

Finally of the four plates exposed to the spray from coughing at a distance of only 15 cm. from the mouth, two were overgrown with alkalin spreaders and so may be excluded from consideration. Of the other two one showed two droplet colonies and the other four. All six on cultivation showed the presence of mouth streptococci.

Altogether it appears from these experiments with the mouth streptococci that normal mouth bacteria are much less easily discharged into the air than are artificial cultures introduced into the mouth. Loud speaking and even coughing did not deposit very large numbers of mouth streptococci even upon plates within 15 cm. of the mouth; and the quantitative examination of 74 liters of air exposed to the spray from loud and vigorous speaking at distances of 35 cm. to 2.4 meters from the mouth failed to show the presence of mouth streptococci in any instance.

SUMMARY AND CONCLUSIONS.

It appears from these experiments, as it appeared in the German investigations which have been reviewed above, that bacteria with which the mouth has been inoculated are discharged in the act of speaking in large numbers, and to considerable distances. Positive results were obtained as far as 7.5 meters from the speaker; and the average number of bacteria discharged over the whole surface of a room (6×8 meters) by 15 minutes' loud speaking was 646 per square meter. These results coincide closely with those obtained by Laschtschenko, Koeniger, and Gordon. A still more extensive spread of mouth spray would of course result from coughing and sneezing.

Most of the particles in the mouth spray are rather coarse and settle out rapidly. In fact the spray is like rain falling through the air, rather than mist suspended in it. Koeniger showed that 60 per cent of the bacteria in the mouth spray disappeared from the air in 10 minutes, while after 20 minutes less than 10 per cent of the original number remained. In estimating aerial infection proper, it is the bacteria suspended in the air which are important because these only could be inhaled with the inspired air. Our second object was to attain a quantitative measure of the extent of such aerial infection; and we found that after inoculating the mouth with a rich culture of B. prodigiosus and speaking loudly and with vigorous enunciation for 15 minutes only seven colonies of the specific germ could be obtained from 140 liters of air collected at the close of the speaking from various points in front of the speaker. The true aerial infection is therefore relatively small by comparison with the distribution of the heavier particles of spray.

Experiments with fresh cultures introduced in large amounts upon the surfaces of the mouth give an exaggerated idea of the quantitative importance of the mouth spray. We therefore attempted finally to control the investigation by a study of the distribution of the mouth streptococci which had been suggested by Gordon as offering a promising test of normal mouth pollution. Gordon easily detected these organisms by exposing plates after speaking for various lengths of time. We found them on plates by similar methods; but even at a distance of only 15 cm. from the mouth of a subject who coughed for three minutes the number of droplets containing mouth streptococci was small. Quantitative tests of the air itself from points 35 cm. to 2.4 meters in front of speakers who spoke vigorously in English or German failed to show any mouth streptococci in 74 liters of air examined.

It might be surmised that in pathological conditions bacteria may be more readily dislodged from the mucous membranes than would be the case under normal conditions. Thus the mouth streptococcus may furnish too low an index for measuring the mouth spray, as the B. prodigiosus furnishes too high a one. Experiments carried out with coughing consumptives by Laschtschenko and Heymann, however, bear out the conclusion that the actual extent of air infection is but small. Out of five air samples of 10 cu.m. each examined by Laschtschenko only two contained tubercle bacilli; out of seven samples of 1 cu.m. each, examined by Heymann, only two gave positive results.

It is not intended to minimize the real danger from mouth spray. Large numbers of bacilli are discharged in coughing by some consumptive patients. Ziesché found in one case 20,000 tubercle bacilli on a glass plate 324 sq.cm. in area exposed for half an hour from 40–80 cm. in front of the mouth of a phthisical patient. The infection by mouth spray of food or of other objects later brought directly or indirectly in contact with the mouth is a real and important danger. Flügge's practical recommendations are fully warranted by all the facts: "During strong paroxysms of coughing, the consumptive should keep at arm's length from his companions and should hold a handkerchief before his mouth. In workrooms, offices, and such places the space between the heads of the workers should be at least 1 meter."

On the other hand all this furnishes no basis for a belief that tuberculosis or any other disease is contracted to an appreciable extent through the inspired air. The mouth spray is a fairly coarse rain which quickly settles downward. Even in artificial experiments with B. prodigiosus the actual extent of air pollution, when quantitatively measured, appears to be small; and when infection by normal mouth streptococci or tubercle bacilli is studied it is much smaller still.

These conclusions are in harmony with the conviction now generally gaining ground that aerial infection of any sort is a minor factor in the spread of zymotic disease; and in regard to tuberculosis they accord well with the opinion that ingestion rather than inhalation is the principal channel of infection even in the case of bacilli originally discharged through the air in the form of mouth spray.

REFERENCES.

BERNHEIM, S. 1908. "Relations de l'air avec la tuberculose; sterilisation de l'air," *Transactions of the Sixth International Congress on Tuberculosis*, I, Part 1, p. 172.

BUCHNER, H., MEGELE, L., AND RAPP, R. 1899. "Zur Kenntnis der Luftinfection," *Archiv f. Hyg.*, 36, p. 235.

CHAPIN, C. V. 1908. "Air Infection of Minor Importance," *Jour. Amer. Med. Assoc.*, 51, p. 2048.

Cornet, G. 1889. "Die Verbreitung der Tuberculose ausserhalb des Körpers," *Ztschr. f. Hyg.*, 5, p. 192.

Flügge, C. 1897*a*. "Ueber Luftinfection," *Ztschr. f. Hyg.*, 25, p. 179.

Flügge, C. 1897*b*. "Ueber die nächsten Aufgaben zur Erforschung der Verbreitungsweise der Phthise," *Deut. med. Wchnschr.*, 23, p. 665.

Flügge, C. 1899. "Die Verbreitung der Phthise durch staubförmiges Sputum und durch beim Husten verspritzte Tröpfchen," *Ztschr. f. Hyg.*, 30, p. 107.

Flügge, C. 1901. "Weitere Beiträge zur Verbreitungsweise und Bekämpfung der Phthise," *Ztschr. f. Hyg.*, 38, p. 1.

Fränkel, B. 1899. "Zur Prophylaxe der Tuberculose," *Berl. klin. Wchnschr.*, 36, p. 21.

Gordon, M. H. 1904. "Report on a Bacterial Test for Estimating Pollution of Air," Supplement to the *Thirty-second Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1902–3, p. 421.

Hamilton, A. 1905. "Dissemination of Streptococci through Invisible Sputum," *Jour. Amer. Med. Assoc.*, 44, p. 1108.

Heymann, B. 1899. "Ueber die Ausstreuung infectiöser Tröpfchen beim Husten der Phthisiker," *Ztschr. f. Hyg.*, 30, p. 139.

Heymann, B. 1901. "Versuche über die Verbreitung der Phthise durch ausgehustete Tröpfchen und durch trockenen Sputumstaub," *Ztschr. f. Hyg.*, 38, p. 21.

Hübener, W. 1898. "Ueber die Möglichkeit der Wundinfection vom Munde aus und ihre Verhütung durch Operationsmasken," *Ztschr. f. Hyg.*, 28, p. 348.

Hutchison, R. F. 1901. "Die Verbreitung von Keimen durch gewöhnliche Luftströme," *Ztschr. f. Hyg.*, 36, p. 223.

Koeniger, H. 1900. "Untersuchungen über die Frage der Tröpfcheninfection," *Ztschr. f. Hyg.*, 34, p. 119.

Laschtschenko. 1899. "Ueber Luftinfection durch beim Husten, Niesen und Sprechen verspritzte Tröpfchen," *Ztschr. f. Hyg.*, 30, p. 125.

Pannwitz, G. 1908. "Social Life and Tuberculosis," *Sixth International Congress on Tuberculosis*, special volume containing a series of public lectures specially prepared for the congress, p. 49.

Schäffer. 1898. "Ueber die Verbreitung der Leprabacillen von den oberen Luftwegen aus," *Archiv f. Derm. und Syphilis*, 44 (Festschrift gewidmet Filipp Josef Pick, II), p. 159.

Tendeloo, N. P. 1908. "On the Channels of Infection in Primary Pulmonary Tuberculosis," *Transactions of the Sixth International Congress on Tuberculosis*, I, Part 1, p. 86.

V. Weismayr, A. R. 1898. "Zur Frage der Verbreitung der Tuberculose," *Wien. klin. Wchnschr.*, 11, p. 1039.

Winslow, C.-E. A. 1908. "A New Method of Enumerating Bacteria in Air," *Science*, N. S., 28, p. 28.

Winslow, C.-E. A. 1909. "The Sanitary Significance of Bacteria in the Air of Drains and Sewers," *Report* of the Sanitary Committee to the National Association of the Master Plumbers of the United States for 1907–1908–1909.

Ziesché, H. 1907. "Ueber die quantitativen Verhältnisse der Tröpfchenausstreuung durch hustende Phthisiker," *Ztschr. f. Hyg.*, 57, p. 50.

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THE DISINFECTION OF WATER AND SEWAGE.

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(Visitor.)

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THE subject of disinfection of drinking-waters and of sewage is in no sense a new one. Almost as early as the nature of infectious diseases and the methods of their communication became known, through the developments of modern bacteriology, the desirability of disinfecting waters in particular was recognized. Attention was first drawn to the practical possibility of such processes through the work of early investigators in connection with the water-supplies of troops in the field. Without going into details of these investigations, it will suffice for our present purposes to note that many disinfecting processes were developed by workers in England, Germany, and France. These processes depended, in the main, upon the application of prepared pellets of the various disinfectants employed, and in general involved the addition first of the disinfectant itself, and later of one or more neutralizing compounds, by which the active disinfectant was destroyed and harmless chemical products alone remained in the water. Compounds of chlorin, bromin, and iodin, copper salts, permanganate, and many other powerful disinfectants were employed in this way. On the whole, remarkably successful results for the purpose in hand were attained, but the processes were necessarily limited to small volumes of water, and were totally unsuited, owing to the nature of the reactions and the cost of the material employed, for application to large city supplies; consequently for many years attempts to purify domestic water-supplies have been confined in the main to sand filtration methods which are now so well known that their discussion at this time is uncalled for. It may be pointed out that these processes are in reality disinfecting processes, since in most cases their chief aim is the removal of pathogenic germs. In the course of the rapid and well-nigh universal development of filtration processes, however, the basic principle of chemical sterilization has never been completely lost sight of. Great stimulus was given to these ideas about a decade ago by the development of commercial processes for the production of ozone. The well-known germicidal properties of this oxygen compound, coupled with the fact that its end-product is ordinary atmospheric oxygen, make the process an ideal one from a chemical and physiological point of view. Commercially, it has always been hampered by the relative high cost of production, by mechanical deficiencies in the machinery necessary for such production, and by certain physical difficulties attendant upon the introduction of the ozone into the water. Therefore, despite the fact that progress in the ozonization of water has been consistent and quite rapid, yet the use of ozone in water disinfection has not become general. It must be particularly noted, however, that the deficiencies of this process are purely mechanical, and that the work of investigation which is going on in many parts of the world may reasonably be expected eventually to develop a process as successful commercially as it is ideal from purely sanitary considerations.

Quite early in the history of the chemical disinfection of water the possibilities of chlorin compounds were recognized. Electrolytic processes for the manufacture of these compounds were developed as early as in 1889, when Webster in England and Woolf in this country attempted the use of electrolyzed sea-water solutions in disinfection work of one kind or another. Here again mechanical difficulties were met with which, combined with the fairly high cost of production, prevented the general adoption of these methods. The commercial production of calcium hypochlorite or bleaching powder had in the meantime been developed to so high a degree of efficiency, owing to the great commercial demand for this product, that sanitarians soon had at their command an extremely efficient disinfectant which could be obtained in any desired quantity at very moderate cost. Attention therefore was early directed to the possibilities of this commercial product, particularly in connection with sewage disinfection. As early as 1854, the Royal Sewage Commission of Great Britain recommended the use of this substance in deodorizing the sewage of London. In 1885 the Special Committee of the American Public Health Association carried out an exhaustive study of all available disinfecting materials, and found that hypochlorites in general were the most efficient substance that could be used, cost being considered. In Germany, at the Hamburg Hygienic Institute, the work of Proskauer and Elsner in 1897, and later of Dunbar and his associates in 1904 and 1905, demonstrated anew the possibilities of hypochlorite of calcium in sewage work, with special reference to disinfection rather than to mere deodorization. At the Royal Testing Station at Berlin work carried out in 1906 confirmed the Hamburg results, and indicated that the disinfection of sewage by this means was entirely feasible. Rideal's experiments at Guilford, England, made about the same time, practically confirmed the German results.

All of these investigations, and more particularly those made in Germany, had reference to the emergency use of chemical disinfection during epidemics, especially of cholera. In such situations questions of economy do not usually arise, and, with their usual thoroughness, the German experts established standards of purification so high that their processes, although eminently satisfactory under the conditions for which they were devised, were still too costly for ordinary every-day use. It remained for the investigators of this country to demonstrate that much lower percentage efficiencies than those obtained previously would still suffice in routine work, and that the cost of obtaining these sufficiently satisfactory results would not be prohibitive. These conclusions were first reached as a result of investigations carried out at the Sanitary Research Laboratory of the Massachusetts Institute of Technology, with which the writer has the privilege to be associated. These studies, which were begun in 1906 and extended over a period of two years, were made possible by the generous co-operation and financial assistance of the United States Geological Survey. They were shortly followed by studies made by Kellerman, Pratt, and Kimberly for the United States Department of Agriculture and the Ohio State Board of Health. The first practical demonstration of the use of bleaching powder on a large scale was made by the State Sewage Commission of New Jersey at Red Bank, under the speaker's supervision. The work was started in October, 1906, and carried on during the fall and a portion of the following summer. Two hundred and fifty gallons of sewage per day were treated at this place. About this same time the writer was retained by the Baltimore Sewage Commission to carry on experiments at Baltimore looking toward the disinfection of the final effluent of the proposed trickling filters now being built at that place. Since that time numerous investigations have been made in all parts of this country, and many working plants have been installed or are now in process of installation. Without exception, the conclusions of the early Massachusetts experiments have been confirmed, and for the first time in the history of chemical disinfection, it has been amply demonstrated that sewage may be thoroughly disinfected at a cost which is not disproportionate to the cost of other purification processes.

Briefly, then, this is the history of the development of chemical disinfection. At the present time the most serious problem is not how to disinfect sewage or water, but rather under what conditions such disinfection is called for, just what the process accomplishes and under what amount of supervision it must be carried out. There is grave danger that, through ignorance of the essential aims and actual accomplishments of this process, it will be misused or employed in situations where its use is uncalled for. Therefore this opportunity to explain the particular work which the process may be expected to accomplish, the peculiar conditions under which it may be properly applied, and its severe limitations, as a general method of sewage treatment, is especially welcome. It must be pointed out at the very outset, and will be reiterated throughout the course of this paper, that the chemical disinfection of sewage or of water is not a panacea. Except under strictly limited and peculiar local conditions it is not even a substitute for other purification methods. In general, it may best be described as an "adjunct," or, to use a term familiar to engineers, "a factor of safety." To the extension and development of this idea, and to a discussion of the actual place of disinfection in sewage and water work, these remarks will be chiefly addressed.

The recent revival of active interest in the possibility of chemical disinfection took place, first, in the field of sewage disposal, and later spread to water purification. It may be well to maintain this order of development, and to consider first the chemical disinfection of sewage and of sewage filter effluents.

DISINFECTION OF SEWAGE.

Sewage consists of about 999 parts of pure water and 1 part of impurity, about one-half of which is organic impurity and bacterial life. Sewage disposal deals with this five one-hundredths per cent. A perfect process of sewage disposal may be defined as one which totally removes and finally oxidizes to a mineral form this very small proportion of organic matter. The slow sand filter, developed to its highest degree of efficiency, can be relied upon under specially favorable conditions to practically accomplish this result. It is possible to produce by such means a water fit for domestic purposes.

The cost of such treatment is high even under the most favorable circumstances, where, as in the case of the Massachusetts towns, large areas of suitable sandy soil are readily available. In less fortunately situated locations, and always among the larger cities, the cost of such a process would be prohibitive. Therefore the tendency of the times as illustrated by the work of experiment stations, and by the effort of municipalities along these lines, has been toward more rapid and less perfect processes. Unfortunately along with this tendency there has come another tendency, namely, toward the standardization of processes, by which is meant a tendency toward the adoption of certain settled types of works regardless of the local requirements. This is a result in part of the unwillingness, and at times the inability, of communities to undertake special investigations of their own or to employ expert assistance. It results also in part from the unfortunate disposition of certain of our State authorities to demand this kind of uniformity throughout their jurisdiction. We have therefore a situation which might be amusing if it were not so serious, in which a designing engineer learns by experience that any plan submitted by him in certain jurisdictions will not receive the necessary sanction of the proper State officials unless certain standard features are incorporated; whereas he is equally well aware that in a neighboring State no plan will be approved which embodies these same standard features. The fact cannot be too strongly emphasized that the solution of any particular sewage disposal problem is one which depends mainly upon the requirements of the local situation. The only conceivable general solution of the problem would be perfect purification, such as has already been defined, and even if this were desirable the result might be obtained by two or more different methods. In general, such purification is unnecessary, and insistence upon it would be a grievous mistake. If partial purification methods are to be allowed, then surely they must be adapted to the requirements in each case. Therefore your attention is first directed to the nuisance which lack of sewage disposal may bring about in order that the method of abatement may be indicated.

One serious nuisance which may follow the introduction of crude sewage into a body of water is the deposit of solid material. Such material we describe as "suspended matter" in the sewage, and one of the classes of treatment to which attention is most often directed has in view the removal of suspended matter from the sewage and the prevention of this form of nuisance. Obviously, now, if the stream is swift and the dilution large, or if the discharge be made into rapidly moving tidal currents, this nuisance will not occur, and special treatment for its abatement will be unnecessary and unwise. Under reverse conditions of discharge into slowly moving streams, particularly into streams which are dammed, or bodies of water which are shallow and do not possess strong tidal currents, the possibility of deposit upon the bottom is one which must be dealt with, and the removal of suspended matter from the sewage must be accomplished to a greater or less degree.

The second kind of nuisance is that which results from the putrescible character of sewage, regardless of whether the organic matter is suspended or in true solution. This is the property of sewage matter by which it robs a stream of its available oxygen, and consequently of its power of self-purification. Under these conditions fish life is destroyed, noxious odors arise from the water, and the stream becomes virtually an open sewer rather than merely a polluted water. The line between these two conditions is a distinct one. The capacity of any stream to absorb sewage and maintain its own aëration is limited and calculable. If this capacity is exhausted, a very definite change in the character of the water occurs and the conditions above outlined result. The treatment of these conditions must be very different from that outlined in the first case. The question of suspended matter may or may not be a factor, but in this case the organic matter must first be oxidized and rendered stable or non-putrescible. The process of oxidation may go on independently of, or in connection with, any other processes, according as one or more of these classes of nuisances is possible.

The third special class of nuisance, and one which refers to public health rather than to public convenience, is the ever present possibility that pathogenic bacteria may be contained in the sewage. The extent of this danger need not be argued, nor is it desirable at this time to take up the somewhat debatable question of the efficiency of our ordinary sewage purification processes in destroying such bacteria. Somewhat divided opinions upon this question are held. The most exhaustive study of the problem that has yet been made was carried out by Houston under the auspices of the Royal Sewage Commission of Great Britain, as a result of which it was concluded that "the biological processes at work in the filters were not strongly inimical, if hostile at all, to the viability of pathogenic germs." It is the speaker's opinion, based upon all the available evidence and upon a long personal experience with investigations of this character, that the removal of pathogenic germs by rapid filtration methods is not greater than would be accomplished naturally in the streams in an equal period of time. That such removal is considerable is frankly admitted. In the course of a few hours or of a day, under natural stream conditions, great improvement is always noted. This improvement, however, has not been sufficient to prevent the disastrous typhoid fever epidemics of Lawrence, Mass., Butler, Pa., Ithaca, N. Y., and other places too numerous to mention. If, therefore, there be any danger in the possible discharge of pathogenic germs into the stream in question, this danger must be considered by itself, and distinctly apart from the possible nuisances already mentioned. It is upon the solution of this particular problem that chemical disinfection directly bears. Whether or not nuisance may arise from the discharge of suspended matter or from the discharge of putrescible matter will determine the type of purification process necessary; whether or not it is desirable to prevent the possible discharge of pathogenic germs into the stream will determine, and must alone determine, the advisability of disinfecting the sewage or the treated effluent.

Emphasis has been laid upon these few general principles, because curiously we are better advised at the present day as to the methods of disinfection than we are as to its necessity. As has been previously stated, there is more danger that the possibility of disinfection will be misunderstood and that processes will be used as a substitute for other essential processes than that it will not be employed when necessary. The various methods of chemical disinfection which have from time to time been proposed have been fully described in another place, and need not be referred to here in detail. Suffice it to say that the application of commercial bleaching powder has been found to be by far the most efficient and practical process, and that such application has now been developed to such a point that its cost is not at all out of keeping with the benefits to be derived.

Bleaching powder is an impure commercial product manufactured in large quantities abroad by some of the earlier chemical methods, and in this country at Niagara by modern electrolytic methods. Owing to the fact that in the latter case it is essentially a by-product of the much more important caustic soda industry, its present market price is very low, and in fact less than the cost of production on a small scale. Upon admixture with water it goes into solution only partially; a residue of carbonate of lime and an excess of free lime remaining in the tank as a white sludge. In practice it is desirable at larger works to keep this mixture stirred up and to discharge the sludge with the solution; at smaller works economy indicates the use of the clear solution and the disposal of the lime sludge in a convenient manner. To the layman one of the most striking features of this process is the relatively small amount of disinfectant necessary. For crude sewage an amount of so-called "available chlorin" equivalent to about five parts per million parts of sewage, which amounts to about 125 pounds of bleaching powder per million gallons, suffices. Upon the present market price of $25 per ton or less, it will be seen that the cost of bleaching powder necessary will be in the neighborhood of $1.70 per million gallons of sewage disinfected. By the use of the quantity indicated, disinfection is accomplished within a very few minutes, and storage periods of not over thirty minutes are ample. Sewage stronger than the average American sewage would require somewhat larger amounts than these indicated, but twice the quantity probably represents the maximum. For partially purified effluents, such as those resulting from trickling filters, lesser quantities are sufficient. At Baltimore three parts per million of available chlorin, or 75 pounds of bleaching powder per million gallons, were found effective in the disinfection of the trickling filter effluent. At Boston satisfactory disinfection of a similar effluent was accomplished through a period of six months by the application of three and a half parts of available chlorin. Effluents of a higher degree of purity can be disinfected with corresponding smaller amounts. The total cost of the processes, including interest charges and depreciation upon the necessary fixtures, labor, and other items, will range from $1.00 or less in the case of effluents to about $3.00 in the case of crude sewages. These details are given in the accompanying table. The results, which have been described as satisfactory, are numerically expressed by removals of the total bacteria, averaging 97 per cent. in the case of effluents and 99 per cent. or more in the case of crude sewage. In the former case the combined efficiency of the filter and the disinfection will bring the figure up to 99 per cent. or more. Special studies have also been made in this connection to show the probable effect upon typhoid fever germs as compared with the effect upon the total bacterial content. The indication has been that the former are affected to fully as great an extent as the latter. They are probably more completely removed.

ESTIMATES OF THE COST OF OPERATION OF A PLANT FOR DISINFECTING SEWAGE OR EFFLUENT WITH CHLORID OF LIME, BASED ON A CAPACITY OF 5,000,000 GALLONS A DAY.

Available Chlorin, Parts per Million.	Bleach, Pounds per Mil. Gal. (Approx.)	Time of Contact, Hours.	Cost per Million Gallons.					
			Fixed.		Operating			Total.
			Storage Tanks.	Other Fixed Charges.	Bleaching Powder.	Labor.	Power.	
1......	25	5.0	$0.10	$0.02	$0.30	$0.10	. .	$0.52
2......	50	2.5	.05	.04	.60	.10	. .	.79
3......	75	1.6	.04	.05	.90	.10	$0.02	1.11
4......	100	1.2	.03	.07	1.20	.10	.02	1.42
5......	125	0.8	.03	.08	1.50	.10	.03	1.74
10......	250	0.5	.02	.16	3.00	.15	.06	3.39
15......	375	0.5	.02	.24	4.50	.20	.09	5.05

DISINFECTION OF WATER.

Considering now the application of these same methods to the water problem, it may be said in brief that the principles involved are identical. Whether or not the chemical disinfection of water is desirable in any given situation must be determined upon principles similar to those already laid down. If the result desired is the simple removal of germs, this process probably represents the cheapest and perhaps the most desirable one now available. The word "perhaps" is inserted here advisedly. The question of just how desirable this treatment may be is one which must be submitted eventually to the consumer who pays the bills. There is a popular objection to the addition of chemicals to drinking-water. This objection was raised most seriously against the use of alum, but has largely disappeared, as the use of alum has become more and more common and as no ill effects have been developed. However harmless certain chemicals may be considered in the minds of those best qualified to judge, and however ill directed popular clamor against their use, it must be admitted that it is a legitimate consideration to be dealt with. Whether or not actual harm will be done is one matter; whether or not the purchaser of the water desires to have small amounts of chemical substances added to his supply (especially if he is willing and able to pay for more expensive processes which do not involve the use of chemicals) is quite a distinct matter. Assuming, however, that, as in the case of alum, any feeling which may be developed at present will disappear in the course of time, it is certainly true that under certain circumstances the chemical disinfection of water may be used to great advantage. As in the case of sewage, so also in the case of water, special consideration must be given to the primary needs of the situation. Disinfection merely kills the germs; if this is all that is required, then disinfection is indicated; if the removal of organic matter from a water seriously polluted with sewage is deemed advisable, then some other process must be employed. If that process is efficient also in the removal of germs, disinfection is uncalled for. If that process, on the other hand, is insufficient, or if economy indicates that it may purposely be made insufficient,—through the use of high rates of filtration, for example,—then disinfection may be advantageously employed to supplement the imperfect process. The two great fields which are open to water disinfection are the treatment of a very slightly or only occasionally polluted supply by disinfection alone, and the treatment of a more seriously polluted supply by the present methods at highly increased rates and by subsequent disinfection. In the latter case disinfection will be found a valuable adjunct to overloaded mechanical filters. The limiting rates of operation on slow sand filters are determined largely by the organic content of the water and by consequent economy in the expensive cleaning processes. The limiting rates on mechanical filters, on the contrary, are practically determined by the necessity for obtaining bacterial purification. Therefore it is especially with reference to this latter type that disinfection will be found important.

Although, as has already been indicated, the chemical disinfection of water has been practised from time to time at various places, the first notably successful plant in this country at least, and the one which is directly responsible for the present favorable consideration which this process has acquired, was constructed and operated early in 1908 by Mr. George A. Johnson, of New York city, at the Chicago stockyards. At this plant the highly polluted water of Bubbly Creek was treated first by chemical precipitation and then by means of bleaching powder. The results of this undertaking were highly satisfactory. Later Hering & Fuller, of New York city, of which firm Mr. Johnson is a member, were called upon to construct at Boonton, New Jersey, on the Jersey City water-supply, a plant for the complete disinfection of forty million gallons of water daily. This plant, which has been in operation since September, 1908, has been so fully described in various papers by Dr. Leal, who is primarily responsible for its installation, by Mr. Fuller, and by Mr. Johnson, that it will be unnecessary to discuss it in detail at this time. It is sufficient to note that the water in question is the somewhat polluted water of the Rockaway River, which has received the advantages of storage and sedimentation in its passage through the immense Boonton reservoir. The results of the continuous operation of this plant have been eminently satisfactory. It might be stated here that the recent litigation in connection with this plant had to do with certain contract requirements rather than with actual results achieved. In Mr. Johnson's report of the operation of the plant it is shown that the bacteria in the water before treatment ranged from a few hundred to a thousand or more, whereas after treatment the water was often found to be sterile, and contained, as a rule, not over ten bacteria per cubic centimeter. The bacillus coli was reported present almost uniformly in the raw water in 1 c.c. tests, and was seldom or never found in the treated water. Quantities of available chlorin not exceeding 0.3 part per million, or eight pounds of bleaching powder per million gallons of water treated, were found efficient. Mr. Johnson estimates the total cost of treatment, including additional labor required, at 14 cents per million gallons. The successful outcome of this great and novel undertaking has resulted in the introduction of this process in at least thirty localities in the eastern United States. The speaker has recently completed the installation and three months' study of a small plant used in connection with mechanical filters. Quantities of available chlorin ranging between 0.25 and 0.4 parts per million were found necessary, and results substantially like those already quoted were obtained, in spite of the fact that the raw water contained at times several thousand bacteria per cubic centimeter.

Here again, as in the case of sewage, the danger is that this process will be misused through a lack of understanding of its possibilities and its rightful field. It is not in general a substitute for filtration. It may be that filters are used where germ removal is all that is necessary. Such filters could be replaced by disinfection methods at an immense saving in the cost. A further danger, which is not so conspicuous in sewage work, lies in the use of this process by inexperienced persons. The proper regulation of the necessary amount of material does not require expert supervision at all times, but the question of how much disinfectant to employ in any given situation, and of the proper method of applying it, and other details of the operation, should in every case be submitted to expert judgment. In addition, the routine operation of the plant should be safeguarded in such a way that the possibility of mistakes should be minimized. As little responsibility and as little chance to go wrong as possible should be left to the operator. In other words, the operation should be made as nearly fool-proof as possible. With these safeguards properly applied, and under the conditions which have been outlined, it can safely be said that a new epoch in water purification methods has begun, and that the methods developed and introduced by Dr. Leal and Mr. Fuller, and especially by Mr. Johnson, have already established their rightful place in the ever growing field of water purification.

REFERENCES.

Sewage:

Proskauer and Elsner: Zeit. Hyg., vol. viii, 1890, p. 62.
Dunbar and Zirn: Vierteljahrsschr. ger. Med., vol. xvi, 1898, Suppl. Heft.
Dunbar and Korn: Ges. Ing., vol. xxvii, 1904.
Schumacher: Idem., 1905.
Schwarz: Ges. Ing., vol. xxix, 1906, p. 773.
Kranepuhl: Mitteilungen aus der Königlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. ix, 1907, p. 149.
Kurpjuweit: Idem., p. 162.
Rideal: Journ. Royal Sanitary Institute, vol. xxvi, p. 378.
Phelps, Earle B., & Carpenter, W. T.: Tech. Quart., vol. xix, 1906, p. 382. Contributions from the Sanitary Research Laboratory, vol. iv, 1908.
Kellerman, Pratt & Kimberly: Bull. 115, Bur. Plant Industry, U. S. Dept. Agr., 1907.
Phelps, Earle B.: The Disinfection of Sewage and Sewage Filter Effluents, U. S. Geol. Survey, Water Supply Paper 229, Washington, 1909.

Water:

Leal, Dr. John: Ann. Rep. Am. Water Works Assn., 1909.
Fuller, Geo. W.: Ibid.
Johnson, Geo. A.: Ibid.

DISCUSSION.

F. Herbert Snow (Harrisburg).—As you know, there is a Pennsylvania law enacted at the last legislative gathering which prohibits the use of alum and copper compounds in food-stuffs. It may be found under one of the sections of the Pure Food Act. The question of whether this law can be extended to apply to treated waters supplied for public uses is a mooted one. It has received some minor consideration, and was the subject of particular inquiry at the time the bill was before the legislative committee. I believe it was generally accepted that the bill if it became a law would not be applicable to mechanical filtration plants where the purification of the water is accomplished in part by the introduction of chemical solutions for the purpose of coagulation and precipitation. Nevertheless, there are occasional and persistent rumors that the law does in fact apply to water, and that alum, if found in water supplied for public uses, is administered contrary to the provisions of law.

It has come to be an accepted fact, generally speaking, that the use of alum compounds as a coagulant in the preliminary treatment of water is unattended with any possible danger to public health where the preparation of the chemical solutions and their introduction into the raw water is accomplished under the supervising direction of a competent person. Nevertheless, I believe that there are many water consumers throughout the towns of Pennsylvania who still adhere to the opinion that this use of alum is a menace to public health, and no amount of proof would convince some of them that this was not so. In fact, there have been known cases where the raw water was not capable of absorbing the chemical solution of alum compounds, and undoubtedly the solutions reached the homes of the consumers substantially in the forms in which they were introduced into the water, although highly diluted. To prevent such carelessness the Commissioner of Health has established a State supervision over all water purification plants in Pennsylvania.

The use of bleach in public water-supplies must bear to the public mind a relation similar to that of the use of alum. The State has discouraged the general application of chlorinated lime to drinking-water. However, in one instance, that of the city of Reading, the Commissioner has approved of the treatment of raw water with hypochlorites of lime under the skilled attention of the city's bacteriologist and chemist, pending the completion of a slow sand filter plant, which will be in operation possibly twelve months hence. Perhaps these few remarks are all that I ought to offer on the subject, in consideration of the position I now occupy. I came here to learn what Professor Phelps might have new to offer on the subject, since he is working in this field all the time. I might add that should you peruse the decrees of the Commissioner of Health relative to sewerage and sewage disposal since 1905, you would observe in the conditions and stipulations under which plans have been approved the provision, sometimes specifically stated, for the treatment of the effluent with some germicide. At Mt. Alto, where the State sanatorium for the treatment of tuberculosis patients has been built by Dr. Dixon and is now being operated, the effluent from the sewage works has been treated with a solution of bleach since the outset, with the result that not one sewage organism has been found in the final effluent.

GEORGE S. WEBSTER.—It is hoped that the investigations of the use of disinfectants that have been carried on so extensively by Professor Phelps and his associates at the Massachusetts Institute of Technology will greatly simplify the problem of sewage purification, particularly in cities which have large streams of water near at hand. Any method which will tend to simplify the treatment of sewage will no doubt decrease the cost of disposal.

If the solids contained in the sewage can be removed mechanically and the bacterial life destroyed chemically by the addition of a solution of bleaching powder, and results obtained at a reasonable cost which will be acceptable, much has been accomplished to aid the profession in handling this important problem.

GEO. E. DATESMAN.—I do not know that I can say anything to add interest to the meeting, except that the city of Philadelphia has for the last nine months been operating night and day, twenty-four hours every day, Sundays included, an experimental plant that follows as nearly as possible the working conditions that will obtain in a full-sized plant. Various processes have been under observation and almost everything that has been advocated has been tried. A great many things have been eliminated after trial, and it only remains to complete the full cycle of seasons to determine certain fluctuations and certain other factors which may be applied in the design and construction of a full-sized plant, as far as the local conditions are concerned. But these factors cannot be taken as applying to other conditions unless the character of the sewage and the other problems that arise are similar.

Something has been done in the way of disinfection, principally in finding out mechanical difficulties. We have not yet determined the minimum amount of bleach that should be added to obtain satisfactory results, but are hopeful of accomplishing this in a short time. As Professor Phelps has said, "there are certain difficulties which arise in the application of bleach through small orifices, due to the deposits of a calcareous nature in the receptacle, appearing as a white sludge and almost in quantity as much as the original bleach," if I am quoting him correctly. We found this to be true, and made no less than five different devices to overcome it, and owing to the persistence and ingenuity of the engineer in charge of the testing plant, I feel sure he has accomplished it. I am led to make this statement because a member of one of the largest consulting engineering firms in this country was very glad to accept the suggestion and apply it to one of the plants of his own design. We find that bleach attacks brass, iron, platinum, and other metals, and corrodes them very quickly. Even lead, which is attacked less than other metals, suffers in time. This is an important thing in a large plant, and it is hard to determine just what should be used. Vulcanized rubber and glass seem to resist the corrosive qualities, and we have had some little success with fiber.

I feel sure, gentlemen, that Professor Phelps, in his work, has conferred a distinct benefit upon the engineering profession and upon the general public of this country. I am led to this statement not only from the perusal of his articles and having become somewhat familiar with his experiments, but from the view that has been taken by others. I find, in reading foreign periodicals, that the English search with the greatest avidity for anything that comes from his pen, and his writings are spread broadcast throughout the kingdom of Great Britain. I think as Americans we should look with pride on an achievement of this character.

While the modern sewage problem was conceived by an Englishman, it was not until the Massachusetts State Board of Health took up the question and investigated it systematically and made experiments to see what could be done under varying conditions that it was reduced to a commercial basis. The results of those experiments have been gratifying, although on such a small scale. It has been said, however, that if they had a small filter about the size of the secretary's table, they could write a book about it about twice as large as the filter.

Nevertheless our English cousins have taken these experiments of the Massachusetts Board and backed them with millions of dollars to carry out those experiments on a large scale, and to-day all honor is given to their American cousins who have carried out these investigations.

Our government and Board of Health investigations have decided that the bleach is quite the cheapest and most effective germicide. I trust that the investigations will be carried along until we become more positive in the methods of application and may know when to apply it in any method of sewage purification.

There is one other little matter: Professor Phelps says he does not advocate the application of bleach as a panacea or a substitute for other purification processes. He is very modest to make this statement. Many people are carried away by ideas that appear to them as convincing. It does not appear to be so in Professor Phelps' case. But as a matter of satisfaction, I wish to state that the application of this bleach as an experiment sometimes produces unexpected results. During the past week we were driven to the use of bleach for the preservation of our bacteria beds. Our beds were filled with a sludge impermeable to liquids for a depth of perhaps 2 feet. A quantity of bleach, of which I cannot now recall the figures, was put in, and a repetition of the process two or three times was successful in that it restored the beds to their original condition, and while I am not yet able to say whether it lowered the bacterial efficiency, there is no doubt but that on a large sized plant an application of this kind would save several thousands of dollars, and by the knowledge of the efficacy of such application many units can be maintained in service that would otherwise have to be built as an extra precaution.

Henry Leffmann.—The principles applicable to the use of aluminum compounds in food cannot be applied to the use of these compounds in the purification of water, because the aluminum, in most cases, remains in some form in the food; but, in the proper operation of water purification, none is found in the effluent. The practical difficulty in reference to all systems of purification with coagulants is in regulating the supply of the coagulant. This is generally attempted by use of automatic apparatus, but is by no means always successful. I presented some time ago to the Philadelphia Section of the American Chemical Society a short paper, giving data in regard to the operation of an alum-filter plant in one of the large hospitals in this city, showing, by the tests of the effluent in comparison with the applied water, the great irregularity of the alum-feed.

Aluminum sulphate is the coagulant generally employed, and it must not be overlooked that this, by increasing the sulphates in the water, increases the tendency to form a hard scale in boilers.

P. A. Maignen.—As a matter of history I think the name of L'Hermitte should be mentioned. He was probably, after Webster, the first to use hypochlorite in France.

I would like to ask Professor Phelps if he has any information on the taste of the water after it has been treated with bleach and passed through a sand filter. Whether the chlorin does not remain hugging the grains of the filtering materials and afterward give a bad taste to the water?

I am very glad that the subject of the chemical purification of water and sewage has been presented to this Club. I do not know if anybody has anticipated me in demonstrating that the chemical purification of water brings about *ipse facto* its sterilization. This was done in the year 1890.

The facts that have been mentioned to-night by the Professor and by the last speaker must put a fly in our ear about the use of bleaching water. If this material acts so strenuously on metals, even attacking platinum, it behooves us to think that there may be some serious danger in its use.

The prejudice against alum is not based on its use, but on its abuse. The same may be said of the use and abuse of bleach. This objection has always been made and will always exist unless it can be proved that an excess, however great, of the chemical cannot do any harm.

The study of the chemical purification of water deserves our closest attention. It should not be resorted to just to help a filter, as is the case when alum is used with so-called mechanical filters. Chemicals should be selected to purify the water independently of filtration and as if no filter whatsoever were to be used. We ought to spend our money on that which is necessary, namely, the material which does the work, and not in accessories.

There is no reason to limit ourselves to alum or bleach; you have the whole gamut of chemicals from which to choose. Suit the chemical to the particular water or the particular sewage to be treated. Lime, for instance, has been used in sewage purification abroad for a very long time, and it is still used in many places because it is safe and cheap. One of the objections urged against the use of lime in sewage treatment is that it makes a great deal of sludge. But lime plus sludge, if collected, would make a pretty good fertilizer.

One may perhaps not be justified in opposing the use of bleach as a disinfectant for sewage, because the treated sewage is mixed with a large volume of water and there is probably not enough of the bleach left to be appreciable. But I cannot conceive its satisfactory use for drinking water. A small quantity of the chlorin gas in the water passing through filters day after day must ultimately leave traces of the sand, which may give a bad taste to the filtered water long after the chemical has ceased to be added to the applied water.

The subject is well worth being studied by chemical engineers. Do not think that bleach or alum are the only available chemicals. Select the chemical that will do the work in a perfect manner. When entering upon the consideration of a problem of this kind, first ask: Is it wanted? Can it be done? Last of all, How much will it cost? If you put the last question first, you will never make any progress.

We are very much indebted to Professor Phelps for having brought the matter before us this evening. If disinfectants are necessary for water or sewage, they should not be added in the dark, but in broad daylight; not with an apology, but because they do the right kind of work and do it safely.

MR. PHELPS.—Replying to Mr. Maignen's question about the odor, I may say that the odor is a very serious matter to be dealt with. If we get too much bleach, we get an odor anyway. If there is too much organic matter, we are pretty sure to get the odor if we put in the bleach before it goes to the filter. It is not a chlorin odor; it is what we call a vegetable odor. We get around the difficulty by adding the bleach after filtration, and I think that is, on the whole, the best place to add it.

M. R. PUGH.—I would like to ask Professor Phelps whether he has made any investigation as to the effect of bleach on sewage before entering the bacteria beds. I believe that Dr. Dunbar has done some work in that direction in which he found it did not have an injurious effect on the bacterial action, and there were cases in which he seemed to think that an application of bleach before it went through the bacteria beds was more effective than applying it to the effluent finally.

Mr. Phelps.—We have not repeated those experiments. The speaker was correct in quoting Dr. Dunbar. I could never see any reason for doing that. I think the work recently done in Germany was done that way because they had settling tanks in which the sewage was settled before filtration, and they did not have tanks for treatment afterward. We have never followed any such process, because our present system saves about half the bleach.

DISINFECTION OF SEWAGE AND SEWAGE EFFLUENTS.

By EARLE B. PHELPS, *Consulting Sanitary Expert, New York.*

In former days the purification of sewage was commonly understood to mean the removal and final oxidation of practically all the contaminating matter present, including the germ life. The old slow sand-filter was relied upon to accomplish this end, and, although, in the majority of cases, its efficiency is not at all times of the degree indicated, yet effluents can be produced under favorable conditions which approximate drinking water standards. However desirable such results may be, the large amount of land required, about an acre for every thousand inhabitants, makes the price almost prohibitively excessive in the region of large cities. Therefore, the tendency of the times has been toward intensifying the natural process of purification to the end that more sewage may be treated upon a given area. Progress in this direction has been rapid and satisfactory, so that with a modern trickling filter the wastes of 20,000 persons can be adequately disposed of upon an acre of filter surface.

With the increased rate of treatment, however, there has come a consequent deterioration in quality. The removal of bacteria, in particular, has ceased to be one of the chief factors in sewage purification. To what extent pathogenic bacteria are removed by filters of coarse stone is a somewhat debated point at the present time, but it is the writer's belief, based upon many years of experimental study and the perusal of the available evidence, that the removal of pathogenic bacteria by modern processes of sewage disposal is at least not more rapid nor more efficient than that which is observed naturally in a polluted stream. In other words, the same natural processes are at work, and the conditions found in the purifying mechanisms have no especial detrimental effect upon the bacteria in question. This at least is the result of investigations upon the fate of non-pathogenic bacteria of certain specified types which have been studied most exhaustively. Reference is had particularly to the bacillus coli. It has been shown repeatedly that this organism is not destroyed in modern sewage disposal plants to an extent which would have any sanitary significance. It has further been shown under controlable experimental conditions that the resistance of this organism to unfavorable surroundings, to heat, to cold, to chemical poisons, and to simple storage in water, is not much greater, if any, than that of the typhoid bacillus. Therefore, in the absence of any direct evidence to the contrary, it is not only just, but quite necessary, to assume that the fate of the bacillus coli in the various processes of sewage purification is indicative of the fate of its more undesirable relative, the typhoid germ. In summing up the evidence in this matter as presented by English experience, Houston concluded that the biological processes at work in the filters are not strongly inimical, if hostile at all, to the vitality of pathogenic germs.

Granting, then, that these sewage filters present no material barrier against the passage of bacteria from the sewage to the stream, we are confronted by a still more perplexing and unsettled question, namely, the degree of purification which may reasonably and economically be demanded. Sewage purification in the complete sense previously described leaves little to be desired as far as results go; but partial purifications of one kind or another are possible also, and in many cases may satisfy the local requirements. In brief, we can remove suspended solids, which cause offensive deposits in streams unless the flow be always rapid; we can oxidize organic matter which will otherwise produce anærobic or putrescible conditions in a stream unless also the final dilution be sufficiently great; or we can destroy pathogenic germs which might otherwise endanger water supplies or shellfish beds. Finally, we can combine any two or all three of these partial methods.

The adoption of a purification process fitted to the local requirements and going no further than these requirements demand, results in a two-fold good. Communities installing the works are saved unnecessary expense and more communities are finding it possible to purify their sewage, owing to the simplified processes now employed. An example has recently come to the writer's notice. A public institution secured an appropriation of $18,000 for sewage disposal works. Plans and bids were called for and the lowest bids received called for a total expenditure of $22,000 for septic tanks, special pumping apparatus and sand filters. This amount of money was not available, the appropriation lapsed and the work was dropped for a year. A special study of the local requirements showed that by no possibility could any physical nuisance occur below the outfall. The discharge was into tidal waters, the volume of water was great compared with the volume of sewage, and the flow was sufficiently rapid at all times to prevent sedimentation. Extensive oyster beds, however, would be affected by the discharge of crude sewage at this point; furthermore, any large, floating particles would be unsightly. A system involving screening, partial clarification and complete disinfection has been designed for this institution. This system meets the local requirements far better than the first plan proposed, since special care is taken to prevent the discharge of bacteria prejudicial to the oyster beds. The total cost, including the capitalization of the extra operating expenses of the disinfecting process, will not exceed $5,000.

This possibility of adjusting the character of the purification works to its requirements, not only resulted in the saving of public funds, but, what is of vastly more importance, made it possible to put in disposal works which might otherwise never have been installed.

This question of the desirability of disinfecting sewage and effluents has been gone into at some length because, strange as it may appear, we are better agreed at present on the methods of disinfection than we are upon its proper role in sewage purification work. The ever-growing necessity for some kind of sewage treatment, particularly in our larger cities, has led to the development of less and less perfect processes of treatment and the question of sewage disposal has curiously become less and less a matter of sanitation. The prevention of physical nuisances in our streams is now held to be all that is necessary or at least all that is feasible. With the definite knowledge of new processes which make it possible at a reasonable cost to provide bacterial as well as organic and physical purification, the question is bound to arise: "To what extent shall we retrace our steps and again regard bacterial removal as one of the factors of the problem?" The problem is further complicated, as it always has been, by the fact that, while the purification of water directly benefits those who pay for it, sewage purification affects directly only those communities situated further down on the stream. It is, therefore, fortunate that all these matters are being placed more and more in the hands of central state bodies, boards or commissioners of health, who, looking upon the questions involved from the broad viewpoint of public policy, are best enabled to decide to what extent the disposal of sewage shall be carried out. This decision must be rendered upon the broadest of sanitary and economic considerations, and the self-interest of the individual communities must not be allowed to interfere with the general policies laid down by these boards for the public good. More and more, therefore, as the powers and activity of such boards increase throughout the various states, is the opinion growing that our drinking-water streams should be protected, not only from gross physical nuisances, but from serious bacterial infections. It often happens that while typhoid fever is raging in one community, the next community downstream has between its drinking water and the necessarily infected waters of the river, only a poor water filter, oftentimes broken down or greatly overworked. The margin of safety here is too small. It is manifestly unjust to throw upon any water filter the burden of purifying a stream which is being seriously and wilfully polluted and infected by others. This is the position which is being taken by the more advanced of our States, as shown by legislative enactments. It is the position universal among the best sanitarians of the day, and, finally, it is the position dictated by ordinary common sense and by an ordinary spirit of engineering caution. Therefore, it does not seem that one will be charged with undue enthusiasm who holds that, since it is now possible and perfectly feasible to prevent the discharge of pathogenic germs through the sewers of cities into drinking-water supplies of other communities or upon important shellfish areas, that such steps should be taken and will in the very near future be considered essential.

Let us consider now the methods by which disinfection may be brought about and the all-important matter of costs. Among the agents of disinfection, chemical and otherwise, which have from time to time been proposed, and many of which have been used in sewage work, the following may be mentioned: Heat, lime, acids, ozone, the various compounds of chlorine, including chlorine gas, hypochlorites, and electrolytic products, the salts of copper, manganates, permanganates, and various organic substances. In an earlier paper the writer has considered the historical development of sewage disinfection and has gone with some detail into the possibilities and the costs of the variout agents mentioned. It will be sufficient for present purposes to state that all of these agents, save the chlorine compounds and the salts of copper, are prohibitively expensive, and that of the latter two, chlorine in the form of hypochlorites appears to be by far the most economical and satisfactory disinfecting agent. Early experiments with hypochlorites in both England and Germany indicated that very satisfactory results could be obtained on a practical scale. The cost, however, of these processes were still too high for ordinary routine use as compared with the costs of other sewage disposal processes. Investigations made later in this country by the writer and others indicated that the high cost of the German results, in particular, was due to the excessively high standards of bacterial removal demanded. For example, in most of the experiments referred to it was thought to disinfect the sewage to such an extent that the bacillus coli would not be found in one litre of the disinfected water. Since this organism occurs in ordinary sewage in numbers ranging anywhere from 10,000 to 1,000,000 per cubic centimeter it is quite evident that the degree of purification called for in this case is far in advance of any practical requirements. Our own investigations show that it was comparatively easy to secure a reduction of total bacteria and of the bacillus coli amounting to from 95 per cent to 99 per cent, and that beyond this point excessive amounts of disinfectant were necessary. This phenomenon of the resistent minority, as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals or other means. It is, therefore, decidedly more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To put the case concretely, it might be found that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money; 98 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first, or even the second, proposition might develop into a feasible plan, while the last might be prohibitively expensive. From the practical engineering point of view, therefore, it is plainly our duty to achieve 96 to 98 per cent reduction at reasonable working costs rather than to secure the ideal at prohibitive costs.

On this principle, therefore, it was determined to learn to what extent sewage filter effluents, and even crude sewage itself, could be purified at costs which were commensurate with the results and with the costs of other purification processes. For this purpose experiments were carried on at the sewage experiment station of the Massachusetts Institute of Technology for a period of over two years. Simultaneously with these investigations work was also under way on a practical scale at Red Bank, N. J., where 250,000 gallons per day of septic effluent was treated. Also, through co-operation with the Sewerage Commission of the city of Baltimore, experiments extending over about one year were made at the experimental plant there. At Baltimore the effluent treated was from a septic tank-trickling filter system. It will not be necessary to go into the details of these various investigations, which have already been published in full by the United States Geological Survey, through whose financial aid they were made possible. In brief, it was found that the satisfactory disinfection of a trickling filter effluent which has been purified to a condition of non-putrescibility can be accomplished by the application of ordinary commercial bleaching powder in the proportion of three parts per million of available chlorine or approximately 75 pounds of bleaching powder per 1,000,000 gallons of effluent. The removal of bacteria possible in this way will average over 95 per cent, making a combined bacterial efficiency for the filter and the disinfection of between 98 and 99 per cent. The cost of such a process will range from $1 to $1.50 per 1,000,000 gallons, depending somewhat upon the size of the plant and somewhat upon the transportation charges on the bleaching powder. Effluents of higher degrees of purity can be disinfected at still lower costs. Five parts per million of available chlorine, or 125 pounds of bleaching powder per 1,000,000 gallons probably represents the maximum amount which would ever be required for the treatment of effluents of a poorer quality. The disinfection of crude sewage to the same final condition as that mentioned above, namely, the removal of over 98 per cent of its total bacteria, may be accomplished by the application of from five to ten parts per million of available chlorine, or from 125 to 250 pounds per 1,000,000 gallons of bleaching powder, the amount depending upon the character of the sewage. The cost will range correspondingly from $1.50 to $3.50 per 1,000,000 gallons.

The disinfection of septic sewage required the application of from ten to fifteen parts per million of available chlorine, or of from 250 to 375 pounds of bleaching powder per 1,000,000 gallons. If no further purification is required than that given by the septic action and the disinfection, it will probably be found advantageous to reverse the processes, disinfecting the crude sewage before it enters the septic tank. The resulting development of ordinary bacteria within the tank is of no sanitary significance, and it is doubtless of some advantage in the subsequent purification of the organic matter in the stream to discharge an effluent rich in bacteria which assist in that purification. The removal of the bacillus coli in all of the above cases is usually somewhat more complete than that of the total bacteria cited.

Under the conditions of a laboratory experiment, the results of hypochlorite disinfection on both the colon and the typhoid bacilli, carried out under exactly the same conditions, were identical. It seems reasonable, therefore, to assume that the viability of the typhoid germ under working conditions in practical sewage disinfection is at least no greater than that of the colon bacillus, and, therefore, no greater than that of the sewage bacteria as a whole. Consequently, the disinfection results obtained with the total bacteria may, in the case of chlorine disinfection at least be referred directly to the typhoid bacillus with assurances of reasonable accuracy and of some margin of safety.

In the investigations made, the subject of electrolytic processes of treatment received considerable attention. Many such processes have been developed, and a few have actually been installed. The claims of some of them are so ridiculous that the process disbars itself from scientific consideration. There seems to be something about such terms as "electrolytic" which appeals strongly to the layman, and this weakness on the part of local boards of public works has been played upon in many instances for the purpose of marketing certain patented processes of very dubious merit. At the same time there are electrolytic processes for the manufacture of chlorine which are undoubtedly successful, and, in fact, most of the bleaching powder which we use in this work is made by an electrolytic process at Niagara Falls. It happens, however, that chlorine is practically a by-product of the much more important alkali industry and that its price is consequently fixed at almost the cost of materials and freight. Granting to such a process free power and theoretical efficiencies, the cost of manufacture on a scale small enough for an ordinary sewage disposal plant would still be above the market price of bleaching powder. Therefore, one is not mistaken in stating that under present market conditions chlorine can be purchased much cheaper than it can be made even under the most favorable circumstances.

In conclusion, the following table of the total costs of operation, including interest on installation, is given. It is based upon the plant having the capacity of 5,000,000 gallons per day, the costs being per 1,000,000 gallons. In general, plants of a larger capacity could be run somewhat more economically, while on smaller plants the labor items would probably mount up somewhat faster. The costs, as will be noted, all refer to the amount of available chlorine in parts per million found necessary. In this way the table can be applied to any situation after it has been determined by experiment how much available chlorine will be required to produce the desired degree of disinfection. In a rough way, the figures already given, namely, from two to five parts for filter effluents of varying quality; from five to ten parts for sewages, and from ten to fifteen or more parts for septic sewages, may be used. A special column is given to the matter of storage tanks, since in many locations this item would not be an extra charge, existing tanks being used. As to the application of results obtained in one place to conditions met in another, it may be said that the reactions involved are particularly free from interference on the part of the mineral constituents of sewage, conditions which have not been found in the case of copper. Thus there is reason to believe that the results given here are of practically universal applicability.

TOTAL COST OF OPERATING DISINFECTING PLANT.

Based Upon a Plant Having a Capacity of Five Million Gallons Per Day.

Av. Cl. Parts Per Million	Bleach. Pounds Per Million Gallons (Approx.)	Time of Contact. Hours	COST PER MILLION GALLONS					
			FIXED		OPERATING			
			Storage Tanks	Other Fixed Charges	Bleaching Powder	Labor	Power	Total
1	25	5.0	$0.10	$0.02	$0.30	$0.10	....	$0.52
2	50	2.5	0.05	0.04	0.60	0.10	....	0.79
3	75	1.6	0.04	0.05	0.90	0.10	$0.02	1.11
4	100	1.2	0.03	0.07	1.20	0.10	0.02	1.42
5	125	0.8	0.03	0.08	1.50	0.10	0.03	1.74
10	250	0.5	0.02	0.16	3.00	0.15	0.06	3.39
15	375	0.5	0.02	0.24	4.50	0.20	0.09	5.05

WATER POLLUTION
AND
WATER PURIFICATION
AT
JERSEY CITY, N. J.

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NEW YORK, N. Y.

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WATER-POLLUTION AND WATER-PURIFICATION AT JERSEY CITY, N. J.

C.-E. A. Winslow.*

Presented March 16, 1910.

The case of the Mayor and Aldermen of Jersey City, N. J., against Patrick H. Flynn and the Jersey City Water Supply Co., has been debated in the courts for a period of nearly four years, and during this time many questions of considerable interest have been raised in regard to water-pollution and water-purification. As a water-supply case, I think it will perhaps take rank in the history of the subject as second only to the great Chicago-St. Louis case.

The contract originally made between the defendants and the city provided that the works should be "so constructed and maintained by the contractor that the water delivered therefrom shall be pure and wholesome and free from pollution deleterious for drinking and dometic purposes during the time that Jersey City shall take water by the million gallons. If such works and supply are purchased by Jersey City they shall be delivered to said city as a completed operating plant free from pollution, as aforesaid." That was the real crux of the contract which was the subject for debate in the case. The question came before the courts as a result of the expressed desire of the city to purchase the water-works. It was provided in the contract that the city should have the right to purchase these works at a fixed price ($7,595,000), if all the conditions outlined in the contract had been fulfilled; and the main question at issue was whether, first, the system was calculated to deliver pure and wholesome water, and second, if not, what deductions should be made from the contract price to make good the deficiencies of the supply. There were clearly implied provisions in the contract, and in understandings arrived at between the parties, that sewerage systems and sewage-disposal works should be "constructed or arranged for by the contractor to prevent pollution or to carry off pollution existing in the watershed."

The general conditions of the watershed can best be understood from the map (Fig. 1). The supply is derived from the Rockaway River,—one of the three or four large rivers that flow through the eastern part of New Jersey,— and the watershed above the reservoir has an area of about 122 square miles. On the river, near the reservoir, are three towns of some importance and also a number of villages, the rest of the watershed being occupied mainly by wooded land or by grazing and agricultural country. The principal towns on the watershed are Boonton,—right at the point where the river enters the reservoir,—Rockaway, and Dover; and a smaller settlement of particular importance is the little mining village known as Hibernia, on a stream which runs into the Rockaway River, near Rockaway. The population of Boonton is about 4,000; of Dover, 6,300, and of Rockaway, 1,600; total population on the watershed above Boonton is 169 persons per square mile. The slope of the watershed in the vicinity of the river is quite steep; in fact, in the town of Boonton and in parts of the town of Dover the river practically flows through the bottom of a sort of bowl, densely populated, and with every facility for introducing pollution into the stream. There were no public sewers in any of these towns. It was shown, however, in evidence introduced in the case, that a number of private sewers discharged from buildings into the stream and that the storm drains through the towns received considerable direct additions of sewage from privy-vaults and cesspools, which are of course bound to overflow at times. The village of Hibernia presented, at the time the suit was brought, a particularly interesting problem of this kind, in so far as it was an excellent illustration of the opportunity for polluting the stream by other ways than the direct discharge of sewage from sewers. Mr. Kuichling described conditions here as follows:

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> "The village or settlement of Hibernia is essentially a mining camp. It contains numerous small houses occupied by the miners and there are about 1,200 to 1,500 people there. Of that number, from 1,000 to 1,200 work underground in the mines during the day. While they are under ground their wastes mingle with the mine drainage water which is pumped to the surface and flows into the brook that runs through this little settlement or village. This village is in a narrow valley with steep hillsides. These houses are not of a high class of construction. They have, many of them, privies adjacent to runways for water—what would be called a water course or depression in the ground not containing running water. Some are only running brooks and rivulets. Pig pens and hen coops and stable yards generally, are located so that the drainage flows off readily. The water in the Hibernia brook is discolored and visibly and palpably polluted, both from what surface water there is as well as from the mine drainage. One of the mines delivers water that is as discolored and opaque as almost any city sewage."

These conditions, as to surface drainage, although a little more extreme than those generally occurring in Dover and Boonton, were typical of occasional local conditions in both those towns. They were continued, not only on the main river, but along the numerous tributary brooks, some of which are shown on the plan, but most of which are not shown. All these brooks and runways, whether they carried water in dry weather or not, were for practical purposes a part of the stream; that is, from privy-vaults located near those brooks the pollution could be carried very rapidly, at times of flood, through these natural runways into the river. It was maintained by experts in the case that any privy-vaults and cesspools within 1,000 ft. of the bank of the stream or of the tributaries might constitute a source of pollution if they were not carefully looked after.

Analytical data showed the Rockaway River to be highly polluted all along its course, the pollution varying but being always considerable, and sometimes very considerable. The bacterial count at the entrance to the reservoir ranged from a normal value of a few hundred up to 15 or 20 thousand after rain; indeed, the polluted character of the Rockaway River water was conceded on all sides. With the exception of minor discussions in regard to the extent of the surface-pollution, and the part played by the agricultural land and the towns in causing that pollution, the main point of contest was in regard to the purifying-efficiency of the reservoir, which is a large one, as shown on the map. It is a little over two miles long and a mile wide, and the greatest depth is about 85 or 90 feet. It contains above the lowest gate from which water can be delivered, 7,300,000,000 gallons, or a supply for 146 days on the basis of the actual consumption of 50,000,000 gallons per day. At first sight such a reservoir would seem to offer ample facilities for self-purification. The water, however, entered the reservoir at one end and was taken out at the other side of the same end, as shown in Fig. 2. The direct line of flow was a comparatively short distance (3,900 feet), and the real question was as to the actual course taken by the water and the degree of purification effected. The discussion of the purifying efficiency of this mechanism is to my mind perhaps the most interesting phase of the first branch of this Jersey City case, and the opinion rendered in regard to it by Vice Chancellor Stevens is an admirable piece of sanitary writing. Few sanitary experts could make such a clear and forcible statement of the fundamental principles,—principles involving a considerable range of hydraulic and bacteriological problems. The Chancellor said:

"The theory is, that when these germs escape from

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them altogether. Lastly, if they tend to float or linger on the surface, they may there suffer from the germicidal action of the rays of light and perish.' In addition to what is here stated, several of the witnesses are of opinion that the longer they remain out of the intestine the weaker and less virulent they become, and therefore the less likely to cause disease.

> "Now it is on this theory that still water is seen to be a better purifier than running water, but in order that still water may, so to speak, do its work, it must have time. A running mountain-stream may carry the germ and be the vehicle of disease 50 miles below the point at which it was discharged into the water."

Then the Chancellor discusses the actual effect of storage in the reservoir. It is conceded by everybody that if the germs remained in the reservoir for the time which is represented by its full storage capacity, the water would probably be in safe condition, but it was shown that when the reservoir was drawn down and when there was a heavy rain on the watershed, the purifying capacity was much less than that calculated. Some of the experts attempted to maintain the position that the water would necessarily pursue a roundabout course, following down one side of the reservoir to the further end and then back again. It was pretty well settled by the floats, however, that in times of sudden rain, water found its way quickly across the end of the reservoir. In this connection, the Chancellor says:

> "This much would seem to be certain: That the current, such as it is, on the principle that the water goes along the line of least resistance, necessarily tends to flow from the mouth of the river towards the gate-house and spillway. If more water is flowing over the spillway than through the gate-house, then the current would be more pronounced in that direction. If the wind is blowing hard from the northwest, this tendency would be augmented. The larger the volume of water flowing in the river the stronger the current. It nowhere appears in the testimony how far down these currents would extend, so far as they are set in motion by the passage of the water toward the spillway. It is at least probable that the friction of the upper currents upon the lower, created either by a considerable wind or by a freshet, would tend to set the lower currents in motion in the same direction, in accordance with the result of Mr. Kuichling's observations in Lake Michigan, and that these currents would be directed toward the gate-house rather than toward the Parsippany dam.
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> "There is a fact in this connection which seems to me

> to be very strong indeed. I called attention to its significance on the argument, and counsel for the water company could not, so far as I could see, explain it away. In the freshet of 1893 and during 108 consecutive hours, or nearly four and a half days, there was discharged at Boonton 9,885 million gallons. The reservoir contains, above the lowest effluent pipe, 7,300 million gallons. What would have become of the water in the reservoir had it then been full? It is absurd to suppose that this immense volume of water would have flowed over the top of the water already there and left it undisturbed. It would undoubtedly have mingled with it and very largely displaced it. There can be no question that in two or three days some of the inflowing water would have reached Jersey City. It will, no doubt, be said that this was an exceptional flow, but the fact is that a very similar freshet occurred only a year or two before.
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> "I will take, however, what was admittedly a normal year, in fact, a year of very moderate and very even flow. The flow of 1906 is illustrated by Mr. Cook on a diagram. It appears therefrom that on March 4th and 5th it was about 900 million gallons per day; on March 6th, 600 millions, and on March 7th, 400 millions. In other words, nearly 2,800 millions of gallons flowed into the reservoir during those four days. This was considerably more than one-third the contents of the reservoir above the lowest point of discharge. Now considering with what velocity the freshet must have entered the stream and how the contour of the bottom must have given direction to its currents, how the friction of the upper strata would have acted upon the lower, is it conceivable that a considerable portion of the river water would not have found its way to the gate-house within a very few days? The freshet occurred in the early part of March. If coincident with a thaw, then the water would have contained the animal matters which had accumulated on the surface during the freezing weather."

That is, under just the conditions which have been found to be most dangerous in general to surface waters, conditions of low storage with a rapid run-off, passing quickly across the reservoir —just the condition that occurred at Plymouth, Pennsylvania, in 1885, and at New Haven more recently—there was a strong probability that the purifying action of the reservoir would break down. Analytical data showed that such was the case. The total number of bacteria is ordinarily fairly low in water collected at the outlet of the reservoir, but the results are notably variable. According to Dr. McLaughlin's examinations made for the Water Company monthly during a period of three years, 5,400 bacteria were found on one occasion; three other samples showed counts over 1,000, and eight others gave numbers between 500 and 1,000. At Jersey City, after passing through the 22-mile conduit, the bacterial condition of the water is of course better, but the same sort of irregularities are manifest. Mr. G. C. Whipple (for the city) found numbers varying between 120 and 2,500 in 1904 and between 210 and 2,400 in 1905; Dr. McLaughlin's results were not very different; and all along, as the Chancellor showed in his review of the evidence, high counts and the presence of colon bacilli were associated with rains on the watershed and sudden rise of water in the reservoir. Melting snow produced high water on December 22, 1906, and on December 26, 1906, I found 2,200 bacteria per cubic centimeter at Jersey City; in the afternoon of the same day, and on the 27th, the numbers fell to normal values of 150 and 200. The reservoir rose again rapidly on March 13th and 14th, 1907. On March 19th I found counts between 600 and 1,200 at Jersey City, and *B. coli* present in one-tenth of a cubic centimeter.

In order to meet these facts the experts of the company fell back on average analyses, and on this basis made out a fairly good case. Taking all samples throughout the year, colon bacilli were present only 7% or 8% of the time, and the average efficiency of storage compared not unfavorably with that of many water filters. The experts for the city maintained, however, that conclusions based on the proportion of samples showing *B. coli* rested on the assumption of unchanging conditions, and did not apply to a varying purifying mechanism like a reservoir. In the Chancellor's words:

> "If 50 samples were taken from the same place on the same day and it were found that *B. coli* were not present in one cubic centimeter in more than 50% of the samples, then the water would be considered good; but if one sample were taken on one day in each week of the year and it were found that on 45 days *B. coli* were not present and on 7 days they were, all that that would indicate would be that on 45 days the water was good and on 7 days it was either bad or, at least, open to suspicion. We certainly would not be justified in concluding that it was unobjectionable during 7 weeks (if a day is to stand for a week), only because it was good for 45 weeks; if, in point of fact, it were found that for those 7 weeks it was bad."

From this point of view, and judging the character of the water by the colon tests made by the company's own experts, the Chancellor concluded that:

> "The water was of doubtful quality in 1904, 7% of the time; in 1905, 5% of the time, and 1906, 8%. This, in days, would

> be, in 1904, 25½ days, in 1905, 18 days, and in 1906, 29 days, or, if we include Prof. Winslow's analysis 31 days."

This careful study of the efficiency of a reservoir in self-purification led, as I have stated, to the conclusion that generally the reservoir worked excellently. At times, if the conditions of water in the reservoir, the stream-flow, wind, etc., were right, the purifying mechanism (generally efficient) broke down and large numbers of bacteria were carried across the intake. It was even claimed by the experts on the city side that on one occasion there was a slight increase in typhoid fever in Jersey City following one of these lapses. The evidence was not conclusive on that point, and the general death-rate from typhoid fever was exceedingly low; in fact, Jersey City has one of the lowest death-rates from typhoid fever in this country. Nevertheless, the evidence was sufficiently clear to convince the Chancellor that there was danger on those few days in the year when conditions were just right to make the reservoir an imperfect purifying-mechanism. Of course, the question whether typhoid fever did or did not follow those breaks had no important bearing on the practical proposition. It might easily be that for a number of years there would not be typhoid bacilli in the Rockaway River at just the right time to be carried across. Nevertheless, if the pollution existed, there was always the chance that at some time the specific infection would be present. As the Chancellor stated the case:

> "I am, on the whole, obliged to conclude that all the evidence favors the theory that water, under certain combinations of circumstances occurring perhaps on an average two or three times a year, will pass from the mouth of the river to the Jersey City reservoirs in two or three days. Every fact is favorable to this view and no fact, so far as I can discover, is opposed to it."

The Court therefore reached the opinion that "Patrick H. Flynn and the Jersey City Water Supply Company have not complied with those provisions of the said contract which stipulated that the supply of water delivered to Jersey City shall at all times be free from pollution, it appearing that the works, as a mechanism for the purification of the supply, are not at all times adequate and reliable."

It was therefore decreed that "There shall also be deducted from the contract price the cost of establishing intercepting-sewers and drains and sewage-disposal works, capable of substantially preventing the contamination of the Rockaway River above the Boonton Reservoir from the sewage of the City of Dover, the City of Boonton, and the Village of Hibernia, which cost shall be hereafter determined by the Court."

It was also provided that the company might "in lieu of and as a substitute for all or any of the sewers and sewage-disposal works . . . present other plans or devices for maintaining the purity of the water delivered by the company to the city throughout the year." Evidence in regard to these plans or devices and their cost, and in regard to the cost of the sewers and sewage-disposal works, was to be presented before a special Master,—the Honorable William J. Magie. This constitutes the second branch of the case, on which the evidence is now all in, but on which a decision has not yet been rendered. The experts for the city have proposed sewage-disposal works of several types. The sewerage plan, which was at last practically agreed upon by experts for both sides, was for a trunk-sewer running down the Rockaway River from Dover to a purification-plant below the Boonton dam. I believe the plan of the company's experts provided for a trunk-sewer on one side and the city's experts on the other, but there was very little difference in either the designs or the estimates. The collecting systems differed in extent, but the revised plans of Mr. Nicholas S. Hill, the principal engineering witness for the city, were only $544,540, against estimates of $376,005 by Mr. Rudolph Hering, and $420,595 by Mr. G. W. Fuller, for the company. For Hibernia, where there is no water-supply available, Mr. Hill proposed a pail-system of collecting and disposing of excreta at an estimated cost of $23,475. Furthermore, the city maintained that the capitalized cost of operation and due allowance for depreciation should also be included, bringing the total deduction up to $872,744.

The company's alternative plan, which was, of course, much cheaper than any sewerage system, was a chlorine-disinfecting plant for treating the water as it was taken out of the reservoir. This plant—which was made possible, I think, by the experiments carried out at "Bubbly Creek" at the Chicago Stock Yards—is described in the *Engineering News* for June 24, 1909. As all its details may not be familiar to the society, I will refer briefly to some of them.

The plant as used at Boonton contemplated no filtration of the water but simply treatment either with chloride of lime, or with hypochlorite of sodium produced by the electrolytic treatment of salt. In either case the action is a simple disinfection.

I should not, perhaps, say that the action is simple, however, because a great many pages of testimony were wasted on the discussion as to whether it was the chlorine that killed the bacteria or whether the chlorine liberated oxygen that killed the bacteria. At any rate, there is no doubt that when hypochlorites are added to water or sewage containing bacteria, a large proportion of the bacteria are killed. The plant involved tanks in which the bleaching powder was dissolved, orifice tanks to which the solution was pumped and from which it was wasted over a waste-weir continually, and a grid through which the solution of bleaching-powder was discharged into the stream of water coming from the reservoir at a number of points, insuring a fairly perfect mixture. The amount of bleaching-powder added at first was 36 pounds per million gallons, equivalent to 1.4 parts per million of available chlorine, and about 4.2 parts per million of bleaching-powder. Gradually the amount was cut down to 5 pounds per million gallons, corresponding to 0.2 of a part per million of available chlorine, or 0.6 of a part per million of bleaching-powder,—a very minute dose for this large volume of water. The result was the production of an effluent in general very low in bacteria. According to the experts for the water company, bacterial numbers ranging from 30 to 1,600 were cut down to an average of 15 per cubic centimeter, and during a period of a little less than three months, the colon bacillus was found by the company's experts only once out of 455 tests (*Engineering News,* LXI, 699). Clearly the bleaching-powder exerted a strong bactericidal action. The city contended, however, that the plant did not fulfill the contract and did not supply a pure and wholesome water throughout the year. This contention, which, of course, is not yet an accepted one, being still before the Chancellor,* was based on several considerations, and in reviewing them I can only be held responsible for my own opinions, as I have not studied all the other experts' testimony in the case on either side.

In the first place, the city maintained that the disinfection-plant at the Boonton dam could not properly be held to constitute a process, alternative to the construction of sewers and sewage-disposal works on the Rockaway watershed. Sewage-disposal and water-purification are not interchangeable processes; both are essential according to modern standards. It was Mr. Hering, I think, who coined the aphorism, "Nothing put into a stream without purification, nothing taken out of a stream without purification." Sewage-purification should keep out the grosser pollution, but water-purification is still required at the other end to remove the incidental pollution that must get into any surface-water. To quote from Mr. Hill:

> "It is not sufficient to boil sewage or treat it chemically and then drink it. Under the special condition of flood following low water and accompanied by westerly wind, with

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*Hon. W. J. Magie, the Master in the case, has recently rendered an opinion, supporting the contention of the water company in regard to the character of the disinfected water and the propriety of substituting a disinfecting plant for sewage disposal works. The final decision of the case of course rests with the Chancellor.

which the present case deals, the water at the dam is not a proper raw water for safe treatment. Jersey City, in order to have a safe supply, must remove gross sewage-pollution and then purify the water at the dam. It is therefore manifestly unjust that the water company should evade the more costly fraction of the necessary burden which it contracted to bear."

Besides this primary contention, that a disinfecting plant could not properly be accepted as "in lieu" of sewage-purification plants, the experts for the city maintained that chlorine disinfection, as practiced at Boonton, did not yield a water "pure and wholesome and free from pollution deleterious for drinking and domestic purposes." For the most part, the water delivered at Jersey City was of excellent quality as judged by the ordinary bacterial tests, but there were still irregularities, which coincided as before with periods of heavy rain on the watershed. For example, near the end of October, 1909, there were severe rains, and on four days following October 26th, several samples of water at Jersey City showed colon bacilli present in 6 or 7 out of 10 one-cubic-centimenter samples. These were only occasional samples, it is true, for others collected on the same days failed to show intestinal organisms; but there were similar findings of intestinal bacteria on January 28, and on March 4, 1909, as shown by the analyses reported by the experts for the city.

OnMarch 4th, the following results were obtained by Dr. Charles E. North:

BACTERIOLOGICAL EXAMINATION OF WATER AT JERSEY CITY, MARCH, 4, 1909.

Sample.	Bacteria per c. c.			*B. coli.*	
	20°	37°	Acid Formers.	Lactose bile.	1 C. C.
				+	—
1	3600	367	200	7	3
2	620	700	220	0	0
3	1800	520	210	4	6

The experts for the Company also noted the pollution of the water on this occasion. Similar excessive numbers of intestinal bacteria were testified to in August, September, and October, 1909, by Doctors Jackson and North, experts for the city. It seemed to me and to others that these high numbers of bacteria were due to the fact that the sudden increase in organic matter sweeping across the reservoir at times of rain was too much for the normal dose of bleaching-powder, and this possibility apparently constitutes one fundamental defect of the process. When a burden of extra organic matter is put on a slow sand-filter, it works with a higher percentage of efficiency than before, but bleaching-powder is markedly decreased in efficiency by the presence of organic matter; that is, it oxidizes many kinds of organic matter before it oxidizes the bacteria. The amount of bleaching-powder must be adjusted to the organic matter and the bacteria in order to get efficient results. In water where the organic matter varies widely, there is danger, unless a large excess of bleaching-powder is added constantly, that a sudden influx of pollution will make the process inefficient. This is the first serious objection that can be brought against this usually excellent process.

The objections that I am pointing out are, I think, of fundamental importance in connection with the general introduction of this practice of water-disinfection. There is no doubt that the procedure of chlorine treatment, as worked out at the Chicago Stock Yards and at Jersey City, marks a great advance in water-purification. It is perhaps the greatest step that has been taken since the Louisville experiments on mechanical filters, nearly ten years ago. At the same time, with every new process, it is important to know the limits within which it can be safely used. The next few years will doubtless be devoted largely to working out these fundamental facts, to ascertain how far and in what ways this procedure can be trusted. The first possibility of danger seems to me to lie in this irregular action in water of widely fluctuating composition.

A second question arises in connection with the effect of the bleaching-powder upon different forms of bacteria,—a very interesting point. It has been generally assumed that all that was necessary to know in order to judge of the sanitary quality of a water was the count of total bacteria on gelatine and the determination of colon bacilli, as it was thought that other bacteria, and whatever other detrimental substances might exist in the water, would behave in a manner similar to the total bacteria and the colon bacilli. This belief is justified in the processes of purification dealt with heretofore, with self-purification and with filtration, including under that term not only artificial filtration but also, of course, natural filtration through the soil. All our water supplies are derived ultimately from surface water running off the surface of the ground or running down through the ground. In both the processes of dilution and of filtration all bacteria and most kinds of organic matter are eliminated together in parallel, and therefore it is fair to take a common, easily isolated, type like the colon bacillus and use that as an index of all the rest. Introduce this new idea of disinfection and the old index ceases to be reliable, because the organic substances in the water do not behave in a manner similar to the bacteria and other types of bacteria do not behave like the colon bacillus.

We recognize three types of resistance to such oxidizing action as that of chlorine,—ordinary vegetative cells, cells with a waxy envelope or of waxy substance, like the tubercle bacillus, and spores like anthrax and *B. sporogenes,* which are still more resistant to the action of the disinfectant. There is danger, therefore, that when the colon bacilli are removed these other types may remain. The amount of chlorine used in disinfecting water would almost certainly not affect spore-formers like the anthrax bacillus, which has several times, in recent years, been transmitted in water to cattle, and might just as well be transmitted to man; it seems probable, too, that it would not destroy the tubercle bacillus which gets into water from the sewage of man and from the excreta of cattle, and which recent investigations have shown to be, to an appreciable extent, a water-born disease.

In the third place, the possibility has appeared in the last few years that water-supply may cause disease in other ways than by transmission of living specific germs. The fact that typhoid fever is by no means the only disease caused by polluted water was shown first in this country by Mr. Hiram Mills, of the Massachusetts State Board of Health, and was enunciated in clear and definite form at the Engineering Congress in 1904 by Mr. Allen Hazen, having since become known as the Hazen theorem. The Hazen theorem is that for every life saved from typhoid fever by purification of water, two or three lives are saved from other causes. This fact has been established, I think. When pure water is introduced, there is a fall in the general death rate much larger than can be accounted for by the fall in the typhoid death-rate. Professor Sedgwick has called attention to the fact that among the specific diseases affected in this way are tuberculosis, pneumonia, bronchitis, and infant mortality. Just how these diseases are affected we do not know. Whether the germ is carried in the water—as seems probable in the cases of tuberculosis or whether there are other substances in the water that have a lowering effect on the vital resistance—which seems perhaps a more probable assumption in the cases of pneumonia and bronchitis—we do not know. But the fact that other diseases than typhoid fever are caused by polluted water makes uncertain the value of a process which simply kills certain kinds of bacteria and does not remove other deleterious substances.

This case will, I think, take its place as one of the historical law-suits in connection with the subject of water-supply, and in closing I will call attention only to what seem to be the two main results.

First, the case led to a full and thorough discussion of the philosophy of self-purification. Of course, the Chicago-St. Louis case was the first great demonstration of the extent of self-purification of streams, and showed that it is an enormous force; also that it is possible to discharge the sewage of a city like Chicago into the water-supply of a city like St. Louis, under the proper conditions of dilution and self-purification, without any increase in death-rate great enough to be demonstrated to the satisfaction of the Supreme Court. In the Jersey City case the shortcomings of purification by dilution were strikingly brought out, and I think that is a very important point in connection with this whole subject. Self-purification, while it is a very real method of water-purification, is yet an unreliable method; conditions in a reservoir or lake are constantly varying, and a purifying-mechanism of this kind that may be ample and efficient for 350 days of the year may fail on the other 15 days—a lesson of caution in the use of this process of self-purification. It is a valuable process, but unless the self-purification is considerable, unless the storage period exceeds two weeks or more at all times, and under all conditions of weather and flow, then the system is not one which is absolutely reliable, and requires another safeguard.

The second branch of the case succeeded in demonstrating the great value of the process of the bleaching-powder treatment, and it is said that today this process is in use in about one hundred plants in the United States. It was shown conclusively, in connection with ordinary water-bacteria and the colon bacilli,—the principal signs of danger in supplies of fairly good quality to start with,—that bleaching-powder would secure excellent purification for almost all the time at a cost so light as to be practically nominal. The estimate made by the experts for the company was perhaps well within the range of probability, but they figured that it would cost them only 14c. a million gallons, which is extremely low. Chlorine is now used, as you are aware, in many cities in conjunction with filters,—at Poughkeepsie, N. Y., and at Indianapolis, in connection with slow sand-filters; and at Little Falls, N. J., Harrisburg, Pa., and a great many other plants, in connection with mechanical filters, where the bleaching-powder process not only introduces an added safety to the water but also cuts down considerably the cost of operation. With chlorine, we need simply add enough alum to get rid of the clay, and where there is little clay and a great many bacteria the amount of alum can be considerably reduced. Chlorine has been used at Corning, N. Y., and Ridgewood, N. J., for purifying well-supplies, and it has been used with great success—as at Minneapolis and Montreal—for treating river-waters. This process marks a great advance in our water-works practice, but it is important that, like other new things, it should not be misused. The practical difficulties having been overcome, the engineers and chemists who have worked with this process are likely to think it will do anything. I do not believe that the bleaching-powder process will work miracles, and that it will be possible, by its use, to turn sewage into drinking-water, but I do believe that it adds a third to our two recognized methods of water- purification, storage, and filtration. My own view of the matter is that with the increasing recognition of the importance of pure water, and of the growing opinion that water causes disease in various ways, at least two of these three safeguards ought to be used; that treating a stored water, a lake water, or a reservoir water—any well stored water—by chlorine or by filtation, will funish a satisfactory supply, and that for a river-water supply which has not been stored, both filtration and bleaching-powder will give the best results. Of course, just how far it is necessary to go in these respects will be shown by practical tests carried on in the next few years. At any rate, it is important that this new process should have as a net result the improvement of the character of our water-supplies; it ought to enable cities with poor water-supplies to get fairlv good ones, and cities which have fairly good water-supplies to get excellent ones, but it ought not to be made a means for lowering sanitary standards by substituting partially purified supplies for those that are well purified.

DISCUSSION.

Mr. A. Bement, M. W. S. E., chairman: We are fortunate in having had presented to us a matter of such vital interest, and I am not sure but what it should bring to us a lesson here in Chicago. We have been disposed to consider, in the past, that we had a very good water-supply and that it could be used without question, but ideas have changed and I think it would be well to take into account the facts that have been presented, when considering our own situation.

Prof. A. N. Talbot, M. W. S. E.: The presentation of this interesting subject brings to mind to all of us, I think, in a new way the great importance of this method which has been developed within the last few years. It is quite possible that the use of bleaching-powder may some day be of advantage to Chicago in treating its water-supply, making the second of two methods which Professor Winslow has stated should be used, an additional safeguard to the storage obtained in the great lake. It seems to me that the Society is fortunate in having the matter presented, so ably and so completely, by Professor Winslow.

Mr. B. J. Ashley, M. W. S. E.: I am deeply interested in the subject of water-purification. An instance of water-pollution came to my notice this week, which I will mention. In a letter from Rochester, N. Y., information was revealed that several neighbors outside of the sewer district had been advised by the local plumbers and, I think, by an architect, that to dispose of the sewage from their houses they could dig large cesspools about 12 feet square and 12 feet deep, with a dividing-wall of brick, laid up without mortar, running through them; and that by drilling a hole some 30 or 40 feet into the ground below the cesspools they could tap them and run the surplus liquid off into an underground vein of water known to be passing below. I regret to say that one of the men who tried to take advantage of that kind of sewage-disposal was an ex-brigadier general. So far as civic conscience is concerned, such an act is little short of criminal. While no doubt they obtained their supply from the city water-main, yet wherever that underground vein penetrated and carried the underground current, the possibility of its affording water-supply for neighboring wells is very manifest, and how many wells may be taking water from this vein, even at some distance away, is not known. I could not refrain from writing to the Secretary of the State Board of Health of New York, stating the case to him, but I did not inform him where this instance was occurring.

In the matter of pollution of streams by sewage, I recall a former statement by Professor Winslow, and I wish to ask him to what degree of dilution are the recognized requirements? I think I recall his saying that a dilution of thirty to fifty parts of water to one part of sewage, or of effluent, was considered satisfactory and would prevent a nuisance.

I am glad to note that throughout the country there is a decided advance in the matter of sanitary conscience. People are beginning to learn—and the death-rate is lessening because they are learning—as we all know, and one reason is because of the attention that is being paid to water-supplies and to sewage-disposal.

Mr. C. D. Hill, M. W. S. E.: The protection of drinking water is somewhat out of my line, but this particular topic was discussed in my presence last summer by Mr. Alvord soon after the experiments were made at Boonton, N. J., and at that time Mr. Alvord suggested that possibly the hypochlorite process could be used for the drinking-water here in Chicago. Some one made the suggestion that it might be applied at the cribs, and the counter suggestion was made that it would be quite practicable to apply the process at the pumping stations. When the pumps are discharging a constant quantity of water—a measured quantity of water—an exact proportionate amount of the disinfectant could be used, and it would be a comparatively simple matter to arrange the mechanism. The suggestion was made that while perhaps the process would be unnecessary at present, if analyses at any time indicated pollution of the water at the cribs it could be put into operation temporarily for use as long as it might be needed.

I infer from Professor Winslow's remarks that he does not approve of converting the sewage of "Bubbly Creek" into drinking-water, but perhaps he would not want to be quoted on that proposition specifically.

Dr. Frederick O. Tonney: Several suggestions have been made this evening which I think are pertinent to the situation in Chicago. The one made by the last speaker occurred to me some time ago and I think it is a valuable suggestion. I think it is quite well established that the city of Chicago has an excellent water-supply, as water-supplies go, but there are some things in connection therewith that are still somewhat unsatisfactory. The cribs supplying the main downtown district, and in fact those supplying most of the districts of the city are showing very good results, as indicated by the analysis in the city laboratory, but according to these analyses there are two stations which will bear watching. One is the Rogers Park pumping-station, the intake of which is located within a short distance from shore. A filtration-plant has been recently installed in that station, but up to the present time the water still shows a rather high colon bacillus content. The typhoid rate in that vicinity has also been higher than in other portions of the city. The other station I had in mind is that supplied by the Sixty-eighth Street or Hyde Park crib. This is the only crib which is located within what may be considered dangerous distance of a sewer outlet. The Seventy-ninth Street sewer is still discharging into the lake within a distance of perhaps two miles, and in addition it is probable that at times the sewage of the Calumet River is carried as far north as the intake. As is to be expected, the bacterial tests show evidence of occasional pollution, although this is of rare occurrence. It seems to me that in these two stations quite satisfactory results might be obtained by the addition of a germicide applied as a temporary measure until the polluting agencies mentioned could be remedied. I think that the hypochlorite treatment offers, as suggested, a valuable remedy in such cases, and it no doubt represents a valuable addition to the accepted methods of water-purification.

Another point which I have in mind, now of interest to the city of Chicago, is bearing upon the germicidal-treatment of water, in connection with the "Bubbly Creek" suit. While, of course, the matter is still in the courts and it is, therefore, hardly proper to draw conclusions from the evidence thus far introduced, yet it occurs to me that this case affords an apt illustration of the danger (a natural tendency as a result of over-enthusiasm) of going too far,—of assuming that the process will do more than the facts warrant. No doubt the hypochlorite-process is valuable for the treatment of somewhat polluted waters,—waters which can still be recommended as proper sources for drinking purposes,—but it seems to me that it is going a step too far to try to convert a fresh sewage directly into a potable water by any process as yet developed on a practical scale. Of course the matter will be fought out in the courts and the best evidence on both sides will be presented. At the time of the decision we shall be in a better position to discuss the points at issue.

The subject presented by Dr. Winslow is a matter of vital interest to us all. Personally my attitude is from the standpoint of a hygienist and physician, and as I am not an engineer, many of the practical phases of the problem are perhaps not as clear to me as they are to some of the members of the society.

Mr. Bement: Concerning our water-supply from Lake Michigan, on a great many mornings, I have observed water in the bath-tub which has come out of the cold-water faucet which was so dark that I could not see the bottom of the tub, and sometimes it has been black. That condition seems to occur after we have had a north or northeast wind, and I have supposed that the trouble was due, in a measure, to the dumping of dredgings in the lake.

Mr. Langdon Pearse: There are several points I would like to speak on. I was connected with the Jersey City work on the city side at the time the suit started and made the sanitary survey of the watershed there under the direction of Mr. George C. Whipple, so I might say I am familiar with every inch of the ground in connection with the case, although I have not been connected with the work since 1904. There is not a sewer on the watershed. As Prof. Winslow showed, there are several towns on the watershed—Dover, with a population of about 6,000; Rockaway, about 1,600, and Boonton, about 3,900.

Hibernia was really the worst place—an iron mine employing about 800 men daily in the workings, and all of their execreted matter was pumped out in the mine drainage into a creek running down into the Rockaway River. At the time, we regarded Hibernia as the place requiring the most immediate attention, but we had not developed any scheme to fix it then. It will probably interest the members here who do not come in contact with such things to explain that, in our sanitary survey, we took the census of every house on the watershed which could in any way drain into the water supply, and listed the provision of sewage. In most cases this meant an inspection of the privy and barnyard. These were all mapped and submitted as part of the evidence. Most of the pollution was scattered. Some of it, of course, came in direct from privy vaults that dumped into the stream and from water closets discharging into it. The latter were mostly concealed, but we found that the water company's inspector had been in collusion with the people he was supposed to stop, and that many things had gone on unknown to the water company, although they were doing their best to prevent pollution.

The question of the pollution of the reservoir at Boonton was interesting, and I am glad to hear what Prof. Winslow had to say on it. We thought at the time, that is, before the float measurements were made, that it was highly probable in time of storm that the pollution from the surface wash as it came down the river might be swept right across the reservoir directly into the city supply. We felt that the water really ought to be filtered, although the turbidity was not very high. At that time disinfection had not been developed for the protection of such a water supply. The question of storage is important, but it would not protect in a case like this.

The question of the cost of treating the water by the use of bleaching powder brings up a question which I would like to ask, "Is the cost of 14 cents computed for the making of the hypochlorites by the electrolytic process with the electric power free, or is it for the use of bleaching powder?" The Boonton reservoir has a massive concrete dam, rock-faced, with an available fall, I think, of over 65 feet. That power usually goes to waste but could be utilized to generate electricity to transform salt into hypochlorite of sodium. If that is being done, the cost at Jersey City would not be comparable to what we would have here, for instance, to treat the Sixty-ninth Street crib, although I suppose the Sanitary District would be glad to sell its power at a cheap rate to make sodium hypochlorite for the sterilization of Chicago's water supply.

In connection with the water-supply of Chicago and the towns on the north shore, Dr. Tonney, Prof. Bartow, and myself have carried on a series of experiments as far north as Waukegan and have studied this question of turbidity which your Vice-President, Mr. Bement, speaks of, and we find it is not so much the distance from shore that is the element involved, but the question of the depth at which waves will affect the bottom. We find beyond forty feet depth that there is not much wave action, although at the time of heavy storms a slight action may be noticed. In thirty feet of water it is more pronounced, and in twenty feet almost every wind stirs up the bottom. This is probably the condition around the Chicago cribs because they are in shallow water, none of them in more than thirty feet, if I remember correctly. There has also been more or less dredge dumping around them in the past and spoil deposited from the water tunnels themselves, which is being stirred up by every wind. In that connection I believe the pollution from the Calumet undoubtedly affects the Sixty-ninth Street cribs at times, and I believe always will do so until the Sanitary Canal from the Calumet to the Sag reverses the flow of the Calumet River.

The question of pollution that Mr. Ashley asked in the case of this Boonton reservoir would not apply on account of the actual lack of sewage facilities on the watershed. It is rather curious that such communities should have grown up for so many years without any sewers, but they did, and still flourish.

In figuring dilution, for instance, as in the case of the Chicago Drainage Canal, which has a dilution much less than the relation of one to fifty, that Mr. Ashley asked about, we stated that there was a dilution of three and three-tenths cubic feet per second for every one thousand inhabitants. If this be figured on a per capita water consumption of two hundred gallons per capita, the dilution is about one to eleven. The statement per capita is more comprehensive than the ratio of dilution in gallons on account of the wide difference in the consumption of water and flow of sewage in different communities. At the Thirty-ninth Street Testing Station we find that the per capita flow varies from two hundred to three hundred gallons per capita daily, with a water consumption in Chicago of about two hundred gallons per capita. At Columbus, Ohio, the consumption of water was about one hundred and twenty gallons per capita, and in Massachusetts some towns run as low as sixty gallons per capita and a few even lower, so we try to express such figures for sewage work, particularly dilution, in cubic feet per second per 1,000 inhabitants. The dilution in the Chicago drainage canal of three and three-tenths cubic feet per second per one thousand inhabitants gives a result that is not a nuisance. It would not be safe to drink it at Lockport, and probably not at Peoria on account of the time limit for self purification.

Mr. Bement: I think there is no question in the mind of any of us here this evening, or any of the citizens of Chicago who have given thought to the matter, but that it is desirable to have the Sag cut-off to carry away the sewage from the Calumet district. I hope it will not be long until it is begun and that we shall have the water flowing through there as soon as possible.

Mr. Charles B. Burdick, M. W. S. E.: There is no question but that the subject which Professor Winslow has presented is of great importance. It should be noted, and I believe that Professor Winslow has emphasized this point, that hypochlorite is not a panacea. A good water must be not only healthful, but pleasing to sight, taste, and smell, and no water is acceptable for the use of human beings that does not posses these requisites. Hypochlorite will not clean a dirty water, although it will practically kill the germ life therein, and therefore, except in case of emergency, its usefulness is confined to clear waters. There are, however, many situations where its use will make a perfectly acceptable water.

The opinion has been quite well grounded among sanitarians that a surface-water should be filtered before it is used for domestic purposes, and the term *surface-waters* includes many waters—particularly from lakes—that are acceptable in every other respect than their germ content. Such waters as these can be rendered entirely acceptable by a treatment with hypochlorite.

There is a further field for the use of hypochlorite in the treatment of shallow-well waters. There are many cases where wells for municipal supplies have been sunk in such situations that the sanitary character of the water cannot be endorsed. There are other situations where the environment of the shallow wells may have been originally good, but where municipal growth has changed the original conditions. Such situations are no doubt legitimate fields for the use of hypochlorite.

Apparently this disinfectant has a further usefulness in the treatment of a filtered water. Our best filtration-plants at times leave considerable to be desired in the sanitary character of effluents, and hypochlorite has evidently been applied as an adjunct to filtration with excellent success. Used in connection with mechanical-filtration, it seems to permit a reduction in the quantity of coagulants used. There appears to be situations, especially in the case of waters of low turbidity, where hypochlorite can be applied in conjunction with the coagulants, and improved sanitary results secured, with a net decreased cost in the purification process. One of the most striking uses of hypochlorite has been its use as a temporary means of correcting quickly a contaminated water-supply. There is no other germicidal remedy that can be so quickly, easily, and cheaply applied.

The paper has been useful in pointing out some of the objections to the use of hypochlorite. Any process that promises so much should be carefully examined, because frequently misuse gives a process a bad reputation. It is quite possible to so overdose a water as to create a medicinal odor, which is a serious objection. I have heard of a case where about ¼ of a grain per gallon produced a perceptible odor, and there are probably many waters which will not stand anything like the amount of hypochlorite that has been successfully used upon the water of the Boonton reservoir.

I am sure it would add to the paper if Professor Winslow would enlarge somewhat upon the effect of overdosing on the general acceptability of the water, and its effect upon the human system.

CLOSURE.

Professor Winslow: In regard to the cost of treating water by bleaching-powder, mentioned by Mr. Pearse, the cost of 14 cents included the price of bleaching-powder. The free power was used in the plant for mixing and other things. Hypochlorite made from salt is now being used, making the cost still less.

One reason why the towns mentioned have not built sewers is because they are waiting for Jersey City or the water company to do it for them. That is one of the unfortunate results of the whole legal complication.

Mr. Ashley asked about the degree of dilution of sewage which might be given as a recognized requirement. The proportion is one to fifty parts of sewage, but this standard of one in fifty was simply a limit beyond which nuisance would not occur, so that a stream would not become a cesspool; it was not, of course, a question of a potable supply.

Referring to the point raised by Mr. Burdick, I do not think there is evidence that would lead one to believe that the slight amount of chlorine left in the water after treatment under ordinary conditions would be sufficient to have any effect on health. But where the amount is considerably in excess of that necessary to do the work, there may be what is called a chemical or medicinal taste or odor, which is really the odor of the chlorine. That happened, I think, recently at Quincy, Illinois, and is particularly liable to occur when the attempt is made (as it was there) to add chemicals to the water in small quantities with rather crude dosing devices; under such conditions larger amounts get in at one time than at other times. Another thing that sometimes causes an odor is the decomposition of organic matter. When chlorine is first applied it often kills the fungi in the water-pipes and as they die and decay they give an odor to the water.

There were two points I was especially glad to have brought out. One of the speakers intimated that my position would imply disapproval of the "Bubbly Creek" project. That is a point which I have been striving to impress on the lawyer for the Stock Yards company all day. He has been asking me questions about it for four hours and I do not know whether I have conveyed the idea to him or not. I am glad, however, to have conveyed it to this meeting.

The other point was in regard to the application of the bleaching-powder process to the Chicago water-supply. One of the things I had strongly in mind when I came to Chicago, and have had ever since, was the hope of getting some people interested in that proposition. This process should undoubtedly be installed at an early date, for it is exactly the thing to make the Chicago water-supply right, in the places where now it is weak. The cost is very small indeed and there is no reason why water from the Rogers Park or Hyde Park cribs should be delivered to Chicago in a doubtful condition a month longer. Where conditions are very bad, as at Montreal, the process has been put in without question. Of course Chicago's supplies are not of that character—they are not grossly, heavily polluted,—but yet they are at times polluted and this condition ought not to exist.

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THE FIELD FOR WATER DISINFECTION FROM A SANITARY STANDPOINT.

BY C. E. A. WINSLOW.*

There can be no doubt that the development of a practical method of water disinfection during the last two years marks an epoch in the art of water purification. No such important step has perhaps been taken since the demonstration of the value of mechanical filtration at Louisville over ten years ago. Mr. George A. Johnson and his associates in the firm of Hering and Fuller, have opened up a new field of engineering practice and have rendered a notable service to the community.

It is curious to see the hope of a process for the disinfection of water realized at last after so many years of fruitless effort. Numerous attempts have been made along this line, with ozone, permanganates, bromine and copper sulphate as the principal chemical agents. Ozone proved efficient from a bacteriological standpoint, but practical difficulties in construction and operation have made its production costly and uncertain. Mechanical improvements are constantly being made, and at any time an economical ozone plant may be designed; but so far this possibility appears not to have been realized. Bromine and the permanganates have never been seriously suggested for the regular treatment of water supplies. Copper sulphate enjoyed a brief vogue a few years ago; but it was soon demonstrated that its efficiency was much less as a bactericide than as an algicide and that its action was easily inhibited by the presence of both organic and inorganic substances.

The possibilities of bleaching powder as a water disinfectant, were, as it seems now, strangely overlooked. Its efficiency in the disinfection of feces had long been known. It was used as an emergency measure to clean the water mains after a typhoid epidemic at Maidstone, England, in 1897. Under somewhat similar conditions it was temporarily applied to the water supply of Lincoln, England, in 1904-5. Sewage disinfection by means of bleaching powder had frequently been carried out in Germany during typhoid and cholera epidemics, and at a few places, as at Brewster,

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N. Y., electrically produced chlorin was regularly used for sewage treatment. For the most part however the amounts of chlorin used for water or sewage treatment were rather large and the process was regarded as an emergency measure, rather than as a routine procedure for water purification.

In 1905 Rideal in England first demonstrated that although absolute sterilization of sewage required large quantities of chlorin, a reasonable purification, comparable to that attained by ordinary processes of filtration, could be attained with very small amounts. Prof. Phelps, at the Sanitary Research Laboratory of the Massachusetts Institute of Technology, and later at Red Bank, N. J. and Baltimore, Md., confirmed and extended these conclusions, and between 1906 and 1909 firmly established the practice of sewage disinfection upon a practical basis.*

The treatment of water supplies by bleaching powder was a different problem however; and the credit for this great advance rests with Mr. G. A. Johnson and his associates, who designed the purification plants at the Chicago stockyards and at Jersey City, N. J. Both of these problems presented unique and interesting features. At the stock yards the attempt was made to purify the water, or more properly, the sewage, in Bubbly Creek so as to make it fit for cattle to drink. Mechanical filtration, combined with copper sulphate treatment proved unsatisfactory on account of the enormous amount of organic pollution. The substitution of bleaching powder gave much better results. In the tests reported in the Engineering Record (Vol. LVIII, 659) bacterial counts between 225,000 and 1,390,000 per cubic centimeter were reduced to between 1 and 55. *B. coli* was generally absent from the filtered water. The cost during the official test was $15.66 per million gallons. The plant has been in operation since the autumn of 1908 and has given satisfaction to the stock yards company, although the City of Chicago does not consider the source of supply a safe one and has passed an ordinance forbidding the taking of such waters.

At Jersey City the problem was quite a different one. A heavily polluted stream, the Rockaway River, flows through a large reservoir at Boonton and is generally well-purified by storage. At times of low water followed by heavy rains, however, polluting material is carried quickly across the end of the reservoir and the purification is inadequate. To meet this condition the East Jersey Water Company, under the direction of Mr. Johnson and Dr. J. L. Leal, installed a chlorin plant for treating the whole supply of Jersey City, 40 million gallons a day. Bleaching powder alone is added, with no filtration, and the small dose of from .2 to 1.4 parts of available chlorin per million reduces the bacteria from 30-1600 in the raw water to an average of less than 15 per c. c., according to the records of the water company's experts.* Free water power is available, reducing the cost to the nominal figures of 14 cents per million gallons (quoting again from Mr. Johnson's estimates).

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*Phelps, E. B. The Disinfection of Sewage and Sewage Filter Effluents. Water-Supply Paper No. 229, U. S. Geological Survey.

The Jersey City plant has been in operation now for over a year. As in the case of Chicago the question whether this particular supply of water is or is not a pure and wholesome one has been extensively debated before the courts. The fact that chlorin compounds exert a remarkable bactericidal action has however been amply established; and the cost of treatment is much less than that of any other system of water purification. Chlorin has been used with apparent success at Poughkeepsie, N. Y., and Indianapolis, Ind., in conjunction with slow sand filtration, and at Cincinnati, Ohio, Little Falls, N. J., Harrisburg, Pa., and many other places as a preliminary to mechanical filtration. In connection with the latter process it is clear from the practical results obtained, as well as from valuable experimental studies at the Lawrence Experiment Station of the Massachusetts State Board of Health, that the cost of treatment can be materially reduced by the reduction in coagulant which is made possible by the use of hypochlorite. Without any filtration at all, hypochlorites have been used for disinfecting suspicious well supplies at Corning, N. Y., and Ridgewood, N. J. The scandalous condition of the Montreal water supply has been greatly improved by a similar treatment and the usual winter epidemic of typhoid cut abruptly short. Altogether it is said that the supplies of some hundred cities and towns are receiving chlorin treatment in some form or other at the present time.

There is no doubt that hypochlorite disinfection has come to stay, as a permanent and important part of the armamentarium of the water works engineer. It is particularly desirable therefor that the field for its legitimate use should be defined, so that it may be protected from the unwise use which so often leads to the discredit of new discoveries. Mechanical difficulties having been successfully overcome, the engineer and the chemist are enthusiastic over the chlorin process. The sanitarian must however have his word as to its bearing on the public health; and he finds that the novel process involves serious problems, to some of which the answer is not yet clear. In studying the results of disinfection both at Jersey City and Chicago, from the standpoint of the city authorities, it has seemed to me increasingly important to formulate a clear conception as to what chlorin can and cannot do.

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*Engineering News, (LXI, 697).

It is quite certain that hypochlorite, added in proper amounts, will produce a very high percentage reduction of ordinary water bacteria and of intestinal forms of the *B. coli* group. Its bacterial efficiency, measured in this way, is equal or superior to that of the ordinary water filter of either type. In order to effect this result however, the amount of disinfectant must be adjusted to the amount of organic matter in the water, since chlorin is taken up by some forms of organic matter more promptly than by the bacteria. Thus Jersey City water has received for much of the time only .2 part of available chlorin per million, while Bubbly Creek water requires 2 parts. The sewage effluent from a trickling filter can be treated with 5 parts and crude sewage with 10 to 15. With sudden variations in organic content there is danger that the process may fail, unless a large excess of chlorin be added at ordinary times, for it is usually impossible to determine such changes until a considerable volume of raw water has passed the purifying works. General experience, both at Chicago and at Jersey City, indicates that with skilled supervision a high degree of purity can be maintained for long periods. The experts for Jersey City were however of the opinion that on several occasions, following sudden rains, polluted water did pass the Boonton works and was apparent on analysis at the city. It is clear that irregularity of operation due to variations in raw water, must be carefully guarded against. All devices are fallible of course, but in the slow sand filter an increase in organic content only increases the percentage efficiency of bacterial purification, and with a mechanical filter it is possible to gauge the amount of alum promptly by turbidity standards and a slight excess would do no serious harm. Too large a dose of chlorin on the other hand would quickly produce odors in the water and the danger of miscalculation is more imminent.

The second point on which further light is desirable in regard to the sanitary value of disinfection, concerns the selective bactericidal action of chlorin. A filter, since its working is mainly mechanical, acts in a general way alike on all bacterial cells. Thus it is fair to take the gelatin count and the *B. coli* determination as typical of the reduction in other forms. With a disinfectant the case is very different. There are at least three distinct grades of resistance to bactericidal agents, manifested respectively by ordinary vegetative cells, by cells provided with a fatty envelope and by true spores. The effect of chlorin upon colon bacilli may be considered as representative of its action upon bacteria of the first class, probably including such organisms as those which cause typhoid, and cholera and dysentery. The bacteria whose cells contain a large amount of fatty material are much more resistant. Thus antiformin, a preparation containing hypochlorite and caustic soda as its active agents, is used as an aid in demonstrating tubercle bacilli in the sputum, because it destroys and dissolves the ordinary bacteria without affecting the *B. tuberculosis*. Just how much chlorin would be necessary to destroy tubercle bacilli in water under practical working conditions we do not know. It would probably be in excess of that ordinarily applied, which is nicely adjusted to secure the destruction of such forms as the colon bacillus. This problem is of no small importance, for Sedgwick and MacNutt have shown that tuberculosis is one of the diseases notably diminished by the substitution of a pure for a polluted water.

Even water polluted from agricultural land may bear this organism, since Jordan and Arms have shown that the feces of cattle frequently contain tubercle bacilli. With regard to the spore-bearing bacteria like anthrax the protection afforded by disinfection is practically nil. The standard text-books place the amount of chlorin necessary to destroy anthrax spores between .1 and 3. per cent, quantities far in excess of anything used in the purification of water. With water supplies of fairly good character the danger of anthrax is of course slight, but when heavily polluted sources are used, anthrax may easily be a water-borne disease, as in the outbreak near Corry, Pa., in 1907, which was due to the fact that cattle drank from a brook polluted by tannery liquor. Exact laboratory determinations must be made of the amount of chlorin necessary to kill tubercle bacilli and anthrax spores under the conditions obtaining in water treatment, before there can be any confidence that it will eliminate either of these disease germs.

There remains finally to be considered the problem of organic pollution in water, which is removed to a considerable extent by the various filtration processes and to a much less degree by chlorin treatment. In view of the supreme importance of living disease